MEMOIR OF THE FACULTY OF SCIENCE, KYOTO UNIVERSITY, SIRIES OF GEOL. & MINERAL. VOL. XXXVI, No. 2, pp. 19—85

Tephrochronology and Paleogeography of the Plio-Pleistocene in the Eastern Setouchi Geologic Province, Southwest Japan

By

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(Received May 23, 1969)

Abstract

The correctly identified pyroclastic layers are the best keys for the regional geologic chronology. Japan is a good field for Neogenic tephrochronology, since the Neogene systems of this country have a relatively high frequency of intercalations.

In Part I of this paper, the tephrochronology of the Plio-Pleistocene series in the eastern Setouchi geologic province, Southwest Japan, is summarized, together with the descriptions of the stratigraphy related to the tephra, lithofacies and horizons of fossils. The individual volcanic ash layer should be correctly discriminated. In order to identify the volcanic ash layers exactly, the writer observed the following features of the volcanic ash layers; namely, horizon, thickness, color, grain-size, internal succession, heavy mineral composition, refractive indices of glasses, shape of glass flakes and paleomagnetic polarity.

Characters of the volcanic ash layers in the Plio-Pleistocene series of Central Japan such as the Osaka, Kobiwako and Tokai groups are shown in Tables 1-5 and Fig. 3.

There are several separate sedimentary basins in the east Setouchi Geologic Province. One of them is of marine facies in part but the others are lacustrine deposits. The correlation was very difficult, but it might be easy where volcanic ash layers are discovered in common in every basin. The three groups, Osaka, Kobiwako and Tokai in the eastern part of the Setouchi Province, have several common volcanic seams, such as *Sakura*, *Azuki*, *Pumice*, *Masugi* and *Yubune*. Hence, the correlation of these three groups was established by means of the tephra.

In Part II, the paleogeographical history of the Central Japan in the Plio-Pleistocene Age is given. It was conceived mainly from the paleocurrent directions deduced from the cross-beddings and the geographic changes in lithology. The lithologic variations were made clear by regarding the volcanic ash layers as time surfaces. The generalized results are shown in Figs. 17-21

The paleocurrent directions in the Setouchi Province changed evidently from the south in late Pliocene to the north in the earliest Pleistocene. This fact indicates that the southern zone of the Setouchi Province began to upheave at this time and that the northern zone began to subside successively. The subsided zone of this period is named "Biwako-Osaka subsidence zone".

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Introduction

Southwest Japan of the Neogene Period has been divided into the following three zonal geologic provinces from the north to the south;

1) Hokuriku-Sanin Province
2) Setouchi Province
3) Nankai Province

The Hokuriku-Sanin Province belongs to the "green tuff region" characterized by voluminous intermediate or basic volcanic materials, while almost all of the Neogene sediments in Nankai Province are terregenous clastics of the Miocene in age.

The Cenozoic strata in the Setouchi Province are divided as follows;

1. Alluvial deposits
2. Terrace deposits
3. Plio-Pleistocene Series (Second Setouchi Series)
4. Setouchi Volcanic Series
5. Miocene Series (First Setouchi Series)

The basements contain various kinds of pre-Cenozoic rock units, namely, Upper Paleozoic rocks, Ryoke granitic rocks, quartz porphyry and so on.

The Plio-Pleistocene series in Setouchi Province are exposed in the foot hills of the mountainlands and are called Kuchinotsu, Oita, Mitoyo, Osaka, Kobiwako and Tokai groups respectively (Fig. 1). The Osaka, Kobiwako and Tokai groups are widely distributed in the separate basins of Kinki and Tokai districts, Central Japan. They yield rich fossils; elephants, plants, diatoms, pollens and molluscs. The stratigraphy of these groups has been worked out by many investigators during the last ten years; HUZITA *et al.* (1951), ITIHARA (1960), FUKAKUSA RESEARCH GROUP (1962), HARATA *et al.* (1963), TAKAYA (1963), TAKEHARA (1961), IBARAKI RESEARCH GROUP (1966), NISHIYAMA RESEARCH GROUP (1967), YOKOYAMA *et al.* (1968), YOKOYAMA (1968), ISHIDA and YOKOYAMA (1969) and so on.

In these studies, the volcanic ash layers and continuous marine clay beds have been appraised as the most important horizon markers. In Part I, the writer has described the various characters of volcanic ash layers intercalated in the Plio-Pleistocene series in Kinki, and summarized the tephrochronology of the Osaka, Kobiwako and Tokai groups. In Part II, the paleocurrent directions deduced from the cross beddings and the paleogeographical history of each sedimentary basin are discussed.

Outline of Plio-Pleistocene Series in Kinki District

The Plio-Pleistocene strata in Kinki district are composed mainly of clastic sediments such as gravels, sands and clays with thin seams of peat and many volcanic ash layers (Fig. 2). The foundation is made of Ryoke Granitic Rocks and partly of the upper Paleozoic rocks of Tamba-Mino Terrain. The Plio-

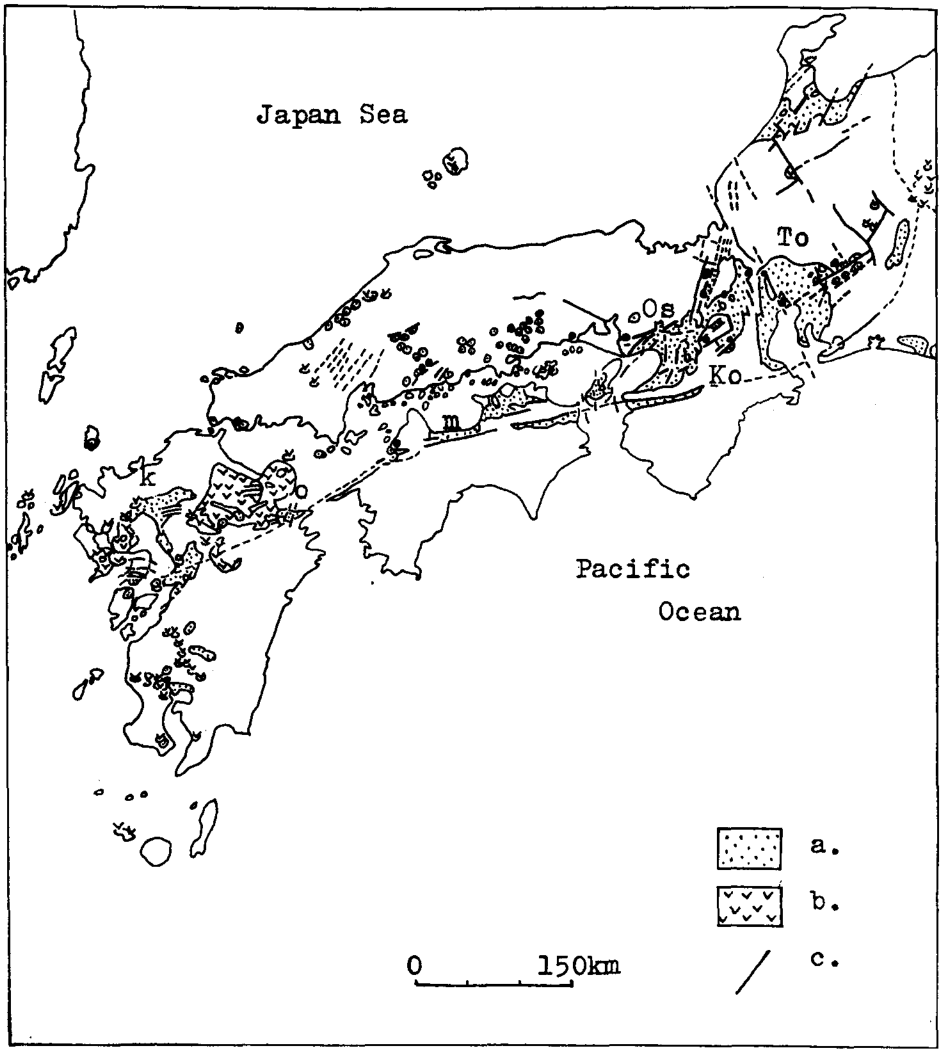


Fig. 1. Distributions of the Plio-Pleistocene series in the Southwest. Japan, a: Plio-Pleistocene series, b: volcanic rocks in Plio-Pleistocene Age, c: fault. k: Kuchinotsu group, o: Ooita group, m: Mitoyo group, Os: Osaka group, Ko: Kobiwako group, To: Tokai group.

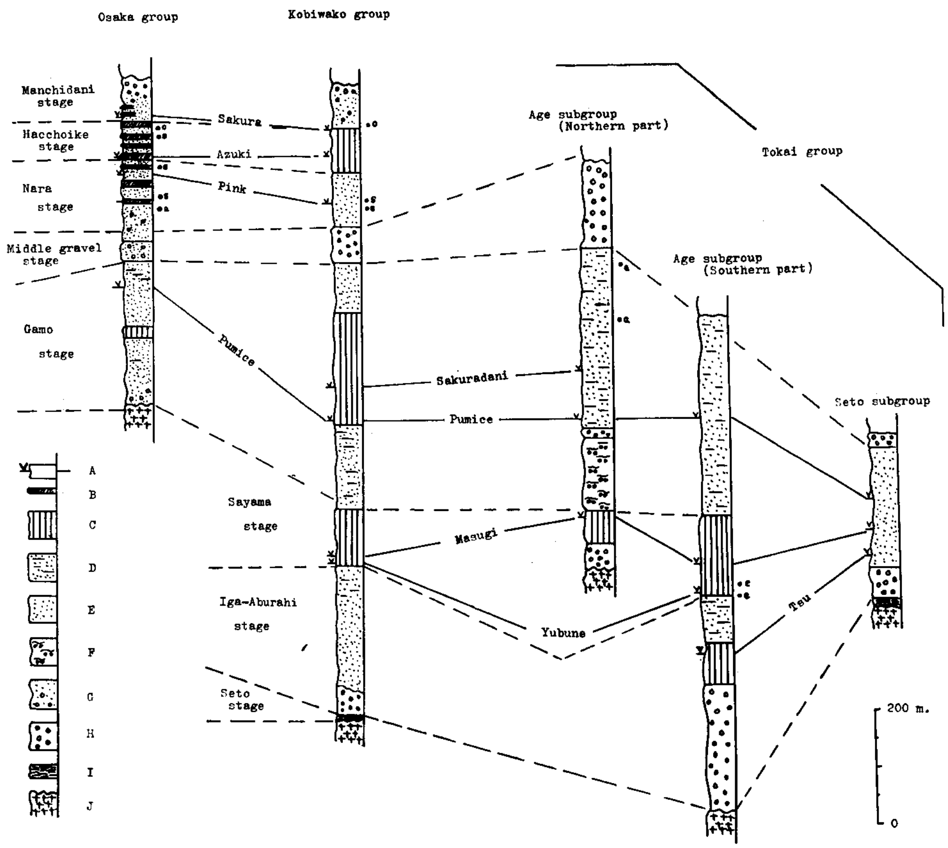


Fig. 2. Columnar sections of the Plio-Pleistocene series in Kinki districts, Central Japan.
A: volcanic ash layer, B: marine clay, C: lacustrine clay D: alternations of sand and clay, E: sand, F: alternations of gravel and clay, G: sand and gravel, H: gravel, I: ceramic clay facies, J: basements.

Pleistocene sequences of this area attain to about 700-1500m in total thickness.

Roughly speaking the sedimentary basins are arranged latitudiually. They are separated by the meridional highlands, for example, Kiso, Suzuka, Shigaraki and Ikoma ranges. There are three independent basins in the Kinki and Tokai districts, that is, Osaka, Biwako and Nobi. Hence we have three group names for the Plio-Pleistocene, namely, Osaka, Kobiwako and Tokai.

1) OSAKA GROUP

The Osaka group occupies Harima, Osaka, Kyoto and Nara basins. The lower part is composed of lacustrine and fluviatile sediments, while the upper part is composed of alternating lacustrine and marine deposits. Most of the marine facies are represented by the continuous clay beds well traceable as horizon markers with characteristic pyroclatic layers. Eight marine clays recognized in the peripheral hill sides are represented by symbols; Ma 1, Ma 2, ···, Ma 7 and Ma 8 in ascending order. Four additional clays Ma 9 to Ma 12 have been found by core examinations of testing wells at several places in the Osaka Plain.

The lowermost portion of the Osaka group yields plant remains such as *Ginkgo*, *Ketereelia*, *Psudolarix*, *Metasequoia*, *Sequoia*, *Liquidambar*, etc., of the late Tertiary Age (MIKI 1948). The assemblage of these fossil plants is called the *Metasequoia* flora (ITIHARA 1960). The characteristic elements of *Metasequoia* flora, with a few exceptions, disappeared during the early Pleistocene from Kinki district. ITIHARA (1960) distinguished between the flourishing age and the extinction age of *Metasequoia* flora. Peat layers of the upper part of the group yielded some forms suggesting a cold climate, for instance, *Pinus koraiensis*, *Menyanthes trifoliata*, *Larix gmelinii*, etc. The lowest horizon of all the beds which contain the cold plant remains is subjacent to the *Kamimura* volcanic ash layer as reported by IBARAKI RESEARCH GROUP (1966). The uppermost part of this group contains a layer with *Sygyzium* and others which existed under a warm climatic condition. *Stegodon orientalis*, *Elephas shigensis* and *Stegodon akashiensis* were found in this group.

2) KOBIWAKO GROUP

The Kobiwako group occupies the Omi and Iga basins. It is divisible into six formations: Shimagawara, Iga-Aburahi, Sayama, Gamo, Yôkaichi and Katata in ascending order. They are composed of lacustrine or fluvial sediments, and yield many lacustrine molluscs akin to the living forms of the present Lake Biwa. *Metasequoia* flora also occurs.

Elephas shigensis and *Stegodon orientalis* are found at the west side of Lake Biwa (Kosei). The horizon of *Stegodon orientalis* is above the *Sakura* volcanic ash layer, and that of *Elephas shigensis* is near the *Pink* volcanic ash layer.

3) TOKAI GROUP

The Tokai group is distributed widely and exposed in the hills surrounding the Nobi Plain and Mie Prefecture. It is composed largely of terrestrial sedimen ts deposited in lacustrine and fluvial environments. The *Pinus trifolia* florais found in the Seto-ceramic clay bed, the lowermost part of the group. *Metasequoia* flora occurs in this group. In Mie Prefecture, *Stegodon elephantoides* occurs in the lower part of this group and *Stegodon akashiensis* is found in the middle part.

Part I

TEPHROCHRONOLOGY AND STRATIGRAPHY OF THE PLIO-PLEISTOCENE SERIES IN THE EASTERN PART OF THE SETOUCHI GEOLOGIC PROVINCE

1) Analysis and discrimination of the volcanic ash layers.

The stratigraphy of the Plio-Pleistocene series in Kinki has been founded on the volcanic ash layers intercalated at intervals of 10-50 m (ITIHARA 1960, TAKAYA, 1963, YOKOYAMA *et al.*, 1968 and ISHIDA & YOKOYAMA, 1969). The volcanic ashes were deposited in lacustrine and internal bay environments. Those in the clay beds are pursuable in the field, even if it is a few centimeters in thickness. The volcanic ash layer indicates a comtemporaneous surface. We can know exactly the relations between the time surface and various geologic phenomena by tracing the volcanic ash layers, for instance, horizontal changes in rock facies and variations in thickness of beds, migrations of basins, reviews of the paleoenvironments and zonations of fossils. In addition to these, the paleomagnetic polarity of volcanic ash layers measured recently (ISHIDA, MAENAKA & YOKOYAMA, 1969) is very interesting. The absolute age can be estimated by means of paleomagnetic age determination. This approach to geologic history, is especially useful for the late Pliocene to Quarternary. MAKIYAMA (1931) claimed that the tuffs can be treated as geologic time surfaces in the survey of the Neogene system of the Shizuoka Prefecture. Also, KOIKE (1956) proposed a new concept "tephrozone" based upon the different proportions of volcanic materials. In this country, the method of tephrochronology was proceeded in the survey of the Kwanto "Loam" and other Quaternary strata in the Kwanto Plain (Kwanto Loam RESEARCH GROUP, 1965) and applied to the corresponding sediments in other districts.

In these works, several tephrozones in the vertical sections of the "Loam" were regarded to be keys for the correlation of topographic surfaces. However, the discrimination of volcanic beds was not perfect. MOMOSE *et al.* (1967) are now trying to determine each pumice fall bed by observation of the patterns of thermomagnetic curves of magnetite in pumice grains. The volcanic ashes and pumices accumulated on land are treated in the main in the tephrochronological works in Japan, but it cannot be applied to the Plio-Pleistocene series in Kinki, since the layers consist of volcanic materials deposited under the water. Although the state of weathering is uniform in the case of the aerial volcanic ash bed, the aqueous ones are infinitely variable in degree of alteration. Attention must paid as to whether the outcrops are new or old. Consequently, compositions of heavy minerals are variable at different sites of the same volcanic bed; that is, magnetites, zircons and apatites become prevalent after a severe weathering, while these minerals are comparatively small in quantity in the fresh part of ash beds.

The aqueous volcanic ash bed is essentially different from the aerial ash bed in the following points;

a. Sedimentary structures

The aqueous volcanic ash layer ordinarily has many primary sedimentary structures such as graded beddings, convolute laminations and cross-laminations. A volcanic layer is often composed of several grading units, that is, a few cycles from coarse to fine. Each cycle of a volcanic set has similar mineral composition in general, and the refractive index of glass is consistent. Each cycle also has its own characteristic features (YOKOYAMA and KUSUKI, 1967).

b. Isopach

The thickness of an aerial ash layer decreases regularly from the source toward the east under the influence of the prevailing westerly wind, so, the isopach line of aerial volcanic materials is generally elliptical, while that of a water-laid ash bed is irregular. Sources of the volcanic ash are seldom made clear.

Analysis of volcanic ash

The volcanic materials, 1/8 - 1/16 mm in size are observed under the microscope. This method of analysis has been already reported by YOKOYAMA and KUSUKI (1967).

a. Heavy mineral

Crystal grains such as biotite, hornblende, orthorombic pyroxene, clino-pyroxene, apatite and zircon are common. Also, magnetite, hematite and limonite are often seen, while olivine is rare. Hyperthene, apatite and some other idiomorphic crystals are frequently wrapped in glass. Colored minerals such as augite, hyperthene and rarely hornblende often show notched edges.

b. Light mineral

Quartz and feldspar are present in some volcanic ashes, but are very scarce in many volcanic beds.

c. Glass

Many volcanic ash beds are composed mainly of glass grains. Under the microscope, the shape of glasses is variable.

There are three types of these shapes, represented as A, B and C. Type A is beautiful glass having no crack and is transparent in general. Its edges are curved or straight. The shape is mostly fan-shaped or triangular, rarely rectangular. Type B is rectangular as usual and has many cracks parallel to the long side. Type C is commonly small and characterized by notched edges.

All of the three types sometimes include a few bubbles. Also, they have tracks of bubbles, even if the flakes have incomplete bubbles only. Such small holes are seen on the surface of feldspar grains too. Type A is further classified into two subgroups; one with linear projections of the surface and the other having no such projection. The above can be summarized as follows;

Type A. Fan-shaped or triangular with linear edge, no crack and generally transparent

Subgroup a.	With linear projections	
	a. With small holes	Type Aaa.
	b. Without small holes	Type Aab.
Subgroup b.	No projection	
	a. With small holes	Type Aba.
	b. Without small holes	Type Abb.

Type B. Rectangular and many cracks parallel to the long side

Subgroup a.	With bubbles	Type Ba.
Subgroup b.	Without bubbles	Type Bb.

Type C. Small with notched edge — Type C.

This method is very useful in the identification of the volcanic ash layers.

Identification of individual volcanic ash

The identification of the volcanic ash is most important for the stratigraphy of the Plio-Pleistocene series in the Setouchi Geologic Province. Formerly, the volcanic ashes were identified by differences in physical appearances, such as coloration, thickness and grain-size. It has been confirmed recently that the vertical change of a volcanic ash layer and the compositions of heavy minerals are useful for identification.

The various characters of the volcanic ashes have been investigated since 1966, and some results have been published in papers with the writer's coworkers: YOKOYAMA and KUSUKI (1967), KAMEI *et al.* (1968), YOKOYAMA & KUSUKI (1969) and ISHIDA and YOKOYAMA (1969).

In this paper, the writer has described the following features of the many volcanic ash layers,

a. Some physical appearances such as color, thickness, and grain-size
b. Internal succession
c. Heavy mineral composition (Tables 1-3)
d. Average refractive index of glass flakes
e. General shape of glass flakes
f. Paleomagnetic polarity.

The main volcanic ash layers are mostly distinguished with aids of above-mentioned features.

2) Volcanic ash layers of the Osaka group

The Osaka group has at least 30 volcanic ash seams. YOKOYAMA & KUSUKI (1969) summarized the characters of the volcanic ashes in the Osaka group, as shown in Table 1. Their name, type locality, horizon, thickness, natural remanent magnetization (NRM) and type of glasses are as follows in descending order, As for the details the reader refers to YOKOYAMA and KUSUKI's paper (1969).

Volcanic ash-layer	thickness (cm)	heavy mineral composition (%)						NRM	index of glass
		oPx	cPx	Am	Bi	Ap	Zr		
Kasuri	5-7	2.3	0.0	97.3	0.1	0.1	0.2	N	—
Neya	10	16.2	5.0	68.1	1.2	0.0	9.5	N	—
Sakura	30	33.5	4.2	55.7	1.6	2.9	2.1		1.504
Fushimi	30	40.3	4.8	45.4	0.6	0.9	8.0	N	1.500
Hacchoike II	5	16.2	11.0	72.7	0.1	0.0	0.0		1.515
Hacchoike I	2	16.7	2.3	77.3	1.0	2.5	0.2		1.505
Imakuma	30	0.0	0.0	93.0	2.5	1.5	3.0	N	1.499
Fukakusa	30	10.4	1.0	75.4	3.4	3.2	6.6	N	1.499
Azuki	30	39.8	21.4	32.1	1.7	3.9	1.1	R	1.511
Yawata		21.5	0.5	78.0	0.0	0.0	0.0		1.501
Kamikatsura	8	9.5	0.0	86.5	4.0	0.0	0.0		—
Yamada II	3	3.4	0.5	94.0	0.6	0.9	0.6	R	1.504
Yamada I	3	18.5	1.1	75.4	0.2	0.6	4.2		1.502
Komyoike		10.5	0.5	88.5	0.0	0.0	0.5	N	—
Pink	40	14.8	1.5	81.5	0.5	0.4	1.3	N	1.498
Ryugaike	15	13.6	0.3	78.1	3.0	4.3	0.7	N	—
Yellow	50	6.2	0.2	70.0	22.1	1.1	0.4	R	1.498
Grey	8	0.7	0.0	92.3	2.7	4.2	0.1	R	—
Kamimura	40	1.9	0.0	73.5	21.9	1.1	1.6	R	1.498
Senriyama	2-5	8.5	0.0	86.5	0.0	5.0	0.0	N	—
Pumice	200	11.0	2.0	63.6	12.7	1.1	9.6	R	1.498
Rotary Ib	10	13.2	3.3	71.3	1.8	5.2	5.2	R	1.503
Rotary Ia	5	10.0	0.6	71.7	0.0	15.5	2.2		—
Shimakumayama	20	24.2	0.3	72.3	1.7	1.3	0.2		1.501
Kokigawa T2	50	62.0	3.5	32.0	0.0	0.0	2.5	N	1.499
Kokigawa T1.5	15	37.5	12.0	49.0	0.0	1.0	0.5	N	1.496

Table 1. Haevy mineral composition and refractive index of glasses of the volcanic ash layers of the Osaka group (average value). oPx: orthorombic pyroxene, cPx: clinopyroxene, Am: amphibole, Bi: biotite, Ap: apatite, Zr: zircon. NRM: natural remanent of magnetization, N: normal, R: reversed. (YOKOYAMA & KUSUKI, 1969)

1. *Kasuri* volcanic ash layer (ISHIDA, 1965)

Type locality: Machikaneyama (campus of Osaka University), Toyonaka City in Osaka Prefecture.

Horizon: bottom of Ma 8 or a few meters under Ma 8.

Thickness: about 5 cm.

NRM: normal polarity.

2. *Neya* volcanic ash layer (YOKOYAMA and KUSUKI, 1969)
Type locality: Neya, Neyagawa City in Osaka Prefecture.
Horizon: between Ma 7 and Ma 8.
Thickness: 5-20 cm.
NRM: normal polarity.

3. *Sakura* volcanic ash layer (ITIHARA, YOKOYAMA and ISHIDA, 1966)
Type locality: Machikaneyama, Toyonaka City in Osaka Prefecture.
Horizon: bottom of Ma 7 or a few meters below Ma 7.
Thickness: 30 cm. (max. 80 cm)
Type of glass: A and Ba.

4. *Fushimi* volcanic ash layer (KAMEI *et al.*, 1968)
Type locality: Kuragatani, Fushimi-ku in Kyoto City.
Horizon: under Ma 6.
Thickness: 30cm (max. 60 cm)
NRM: normal polarity.
Type of glass: Aab.

5. *Hacchoike* II volcanic ash layer (ITIHARA, 1955)
Type locality: Hacchoike (pond), Ibaraki City in Osaka prefecture.
Horizon: in Ma 5.
Thickness: about 5 cm
Type of glass: A, Bb and C.

6. *Hacchoike* I volcanic ash layer (YOKOYAMA and KUSUKI, 1969)
Type locality: Hacchoike at Ibaraki City in Osaka Prefecture.
Horizon: in Ma 5.
Thickness: 1-3cm
Type of glass: A and small quantity of B and C.

7. *Imakuma* volcanic ash layer (ISHIDA and YOKOYAMA, 1969)
Type locality: Imakuma at Sakai City in Osaka Prefecture.
Horizon: between Ma 4 and Ma 5.
Thickness: about 30cm
NRM: normal polarity.
Type of glass: Abb (brown colored)

8. *Fukakusa* volcanic ash layer (Ibaraki Research Group, 1966)
Type locality: Taniguchi-cho, Fushimi-ku in Kyoto City.
Horizon: between Ma 4 and Ma 5.
Thickness: about 30cm
NRM: normal polarity.

9. *Azuki* volcanic ash layer (ITIHARA, 1955)
Type locality: north of Yamada at Suita City in Osaka Prefecture.

Horizon: in Ma 3.
Thickness: 30-50cm
NRM: reversed polarity.
Type of glass: Aab, and Abb with a little amount of brown glasses (Aab), of 2-4%.

10. *Yawata* volcanic ash layer (YOKOYAMA and KUSUKI, 1969)
Type locality: Yawata-cho in Kyoto Prefecture.
Horizon: between Ma 2 and Ma 3.
Thickness: 10cm.
Type of glass: Aab.

11. *Kamikatsura* volcanic ash layer (Nishiyama Research Group, 1967)
Type locality: west of Kamikatsura, Ukyo-ku in Kyoto City.
Horizon: above Ma 2.
Thickness: 5-15cm.

12. *Yamada* II volcanic ash layer (ITIHARA, 1955)
Type locality: Yamada, Suita City in Osaka Prefecture.
Horizon: in Ma 2.
Thickness: about 5cm.
NRM: reversed polarity.
Type of glass: dominant A, common B and a little C.

13. *Yamada* I volcanic ash layer (YOKOYAMA and KUSUKI, 1969)
Type locality: south of Kayano, Minoo City in Osaka Prefecture.
Horizon: in Ma 2.
Thickness: about 5cm.
Type of glass: Ba and C.

14. *Komyoike* volcanic ash layer (ISHIDA and YOKOYAMA, 1969)
Type locality: Komyoike (pond), Izumi City in Osaka Prefecture.
Horizon: between Ma 1 and Ma 2.
Thickness: 20cm.
NRM: normal polarity.

15. *Pink* volcanic ash layer (ITIHARA, 1955)
Type locality: the Suita High School, Suita City in Osaka Prefecture.
Horizon: between Ma 1 and Ma 2.
Thickness: generally 30-50cm.
NRM: normal polarity.
Type of glass: mostly A (Aab) and a litlle amount of Ba.

16. *Ryugaike* volcanic ash layer (TAKETSUJI and ITIHARA, 1967)
Type locality: Ryugaike (pond) at Suita City in Osaka Prefecture.
Horizon: under Ma 1
Thickness: 10-20 cm

NRM: normal polarity.

17. *Yellow* volcanic ash layer (Ibaraki Research Group, 1966)
   Type locality: Meisei, Sakai City in Osaka Prefecture.
   Thickness: 50-100cm.
   NRM: reversed polarity.
   Type of glass: Ba and C.
18. *Grey* volcanic ash layer (ISHIDA and YOKOYAMA, 1969)
   Type locality: Meisei, Sakai City in Osaka Prefecture.
   Thickness: 5-30cm.
   NRM: reversed polarity.
   Type of glass: Ba and C.
19. *Kamimura* volcanic ash layer (Kinki Quaternary Research Group, 1969; the *Upper Senriyama* by TAKETSUJI and ITIHARA, 1967)
   Type locality: Kamimura, Ibaraki City in Osaka Prefecture.
   Thickness: about 30cm.
   NRM: reversed polarity.
   Type of glass: A.
20. *Senriyama* volcanic ash layer I, II (the *Lower Senriyama* by TAKETSUJI and ITIHARA, 1967)
   Type locality: Kamishinden, Toyonaka City in Osaka Prefecture.
   Thickness: I : 2-3cm, II: 3-5cm.
   NRM: normal polarity.
   Type of glass: C.
21. *Pumice* volcanic ash layer (ISHIDA and YOKOYAMA, 1969; T4 by HARATA *et al.*, 1963 and the *Shinden* by TAKETSUJI and ITIHARA, 1967)
   Type locality: Kokigawa, Kaizuka City in Osaka Prefecture.
   Thickness: 100-300cm.
   NRM: reversed polarity.
   Type of glass: A and B.
22. *Rotary* II volcanic ash layer (TAKETSUJI and ITIHARA, 1967)
   Type locality: the rotary in the east of Shimakumayama, Toyonaka City in Osaka Prefecture.
   Thickness: 30-50cm.
23. *Rotary* Ia, Ib volcanic ash layer (*Lower Rotary* by TAKETSUJI and ITIHARA, 1967)
   Type locality: the rotary of the east of Shimakumayama, Toyonaka City in Osaka Prefecture.
   Thickness: Ia: 5-20cm, Ib: 10-20cm.
   NRM: reversed polarity.
   Type of glass: C.
24. *Shimakumayama* volcanic ash layer (TAKETSUJI and ITIHARA, 1967)

Type locality: Shimakumayama, Toyonaka City in Osaka Prefecture.
Thickness: about 20cm.
Type of glass: C.

25. *Kokigawa* T2, T1.5 volcanic ash layer (YOKOYAMA and KUSUKI, 1969)
Type locality: Mizuma, Kaizuka City in Osaka Prefecture.
Thickness: T2: about 10cm, T1.5: 20-50cm.
NRM: normal polarity.
Type of glass: A.

26. *Tsuchimaru* Tla, Tlb volcanic ash layers (YOKOYAMA and KUSUKI, 1969)
Type locality; Tsuchimaru, Kaizuka City in Osaka Prefecture.
Thickness: Tla 10cm, Tlb 20cm.
Type of glass: Aab.

3) Volcanic ash layers of Kobiwako group. There are at least 30 volcanic ash layers in this group.

They are called as follows;

name of volcanic ashes	locality	heavy mineral (%)						NRM	index of glasses
		oPx	cPx	Am	Bi	Ap	Zr		
- Kofoku -									
1. Akatsuki	Akatsuki	1.5	0.0	93.5	5.0	0.0	0.0		
2. Dôkenyama	Dôkenyama	(3)		(24)	(14)				1.498
3. Shiratsuchidani(U)	Shiratsu-	1.0	0.0	96.5	1.0	0.5	1.0		1.498
4. Shiratsuchidani(L)	chidani	2.0	0.0	80.0	15.0	3.0	0.0		1.499
- Kosei -									
5. Minamishô	Minamishô	14.0	0.0	85.0	0.0	1.0	0.0		
6. Minamishô	BW. 54	12.0	0.0	86.5	0.0	1.5	0.0		
7. Minamishô	BW. 55	4.0	0.0	94.5	0.5	1.0	0.0		
8. Sakura ?	Kurihara								1.505
9. Sakura ?	Shimoruge	15.0	22.0	55.0	0.0	6.0	2.0		
10. Sakura	Minamishô	23.0	12.0	43.5	21.0	0.5	0.0		
11. Sakura	BW. 53	32.0	25.5	35.5	5.0	1.0	1.0		
12. Sakura	Kamiôgi	35.0	21.0	39.0	0.5	4.0	0.5	N	1.504
13. Hacchoike	Kamiôgi	29.0	4.0	62.0	0.0	5.0	0.0		1.505
14. Biotite	Kisengawa	13.0	0.0	50.5	33.0	3.5	0.0		
15. Azuki (U)	Kisengawa								1.511
(M) Ki. III*		33.5	26.0	31.5	1.5	7.5	0.0	R	1.509
(L) Ki. I*		44.5	24.0	20.0	1.5	10.0	0.0		1.508
16. Pink	Ogoto	23.0	1.0	60.0	5.0	0.0	11.0	N	
- Konan -									
17. Ishiyama I	Ishiyama	4.0	0.0	88.5	4.0	0.5	3.0		
18. Ishiyama II	Ishiyama	12.0	0.5	81.5	6.0	0.0	0.0		
19. VI	Nango	20.5	1.0	73.0	1.5	0.0	4.0		
20. V	Nango	10.0	0.0	73.0	11.0	2.0	4.0		
21. IV (Pumice)	Nango	13.0	1.0	80.0	1.0	0.0	5.0		
22. III	Nango	1.5	1.0	96.5	1.0	0.0	0.0		
- Kotô -									
23. Kitawaki (M)	Kitawaki	15.0	2.0	82.0	0.0	1.0	0.0		1.500
(B)		13.0	5.0	76.5	2.0	2.5	1.0		
24. Naka	Naka	49.5	0.0	49.5	1.0	0.0	0.0	N	1.498
25. Ikenowaki	BE. 249	39.0	0.5	55.0	0.0	5.0	0.5	N	

name of volcanic ashes	locality	heavy mineral (%) oPx	cPx	Am	Bi	Ap	Zr	NRM	index of glasses
26. Ikenowaki	BE. 250	2.0	0.0	94.0	0.0	2.0	2.0		
27. Hara	Hara(BE. 282)	79.0	0.0	21.0	0.0	0.0	0.0	R	1.502
28. Hara	Hara(BE. 283)	85.0	0.0	13.0	0.0	0.0	2.0		
29. Kono III	Kono								
30. Kono III ? (M)	Sakuragawa	35.0	0.0	61.0	0.0	0.0	4.0		
(L)		59.5	0.0	39.5	0.5	0.0	0.5		
31. Kono III	Kono(BE. 291)	23.0	1.0	41.0	4.0	0.0	31.0		
32. Kono III	Nishioji	58.0	0.0	37.0	0.0	0.0	5.0		
33. Kono II	Nishioji	0.0	0.0	100	0.0	0.0	0.0		
34. Kono I	Nishioji	2.5	0.0	93.0	2.5	1.0	1.0		
35. Sakuradani	Sakuradani	22.0	9.5	63.5	0.0	5.0	0.0		
36. Sakuradani (L)	Tenjincha	34.0	0.5	58.5	5.5	0.0	1.5		
(B)		36.5	0.5	58.5	2.5	0.0	2.0		
37. Mushono (M)	Shinjô	(4)		(22)		(1)	(6)		
38. Mushono (M)	Mushono	5.5	1.0	53.0	17.5	0.0	23.0	R	1.498
(B)		1.5	0.0	86.5	8.0	0.0	4.0		
39. Komazuki	Kaigake	23.0	1.5	75.5	0.0	0.0	0.0	R	1.504
40. Komazuki	Nakahazama	13.5	0.0	82.5	0.0	3.5	0.5		
41. Komazuki	Kamihazama	13.0	2.0	85.0	0.0	0.0	0.0		1.504
42. Komazuki	Komazuki	10.5	0.0	88.0	0.0	1.5	0.0		
43. Hazama	Katayama			(65)		(3)	(4)		1.498
44. Naiki II	Naiki	80.0	0.0	19.0	0.0	0.0	1.0		1.503
45. Naiki ?	Kaigake	8.0	0.0	89.0	0.0	0.0	3.0		1.504
46. Naiki I	Kitasunagawa	53.0	0.5	45.5	0.0	1.0	0.0		
47. Naiki I	Minamihizusa	52.0	0.0	48.0	0.0	0.0	0.0		
48. Kaigake	Kaigake								1.500
49. Kamide	Kamide	63.0	4.5	4.0	27.5	0.0	1.0		1.496
50. Kamide	Mushono	52.0	4.5	15.0	28.0	0.0	0.5		1.496
51. Kosaji	Omigakuen	11.0	0.0	89.0	0.0	0.0	0.0		
52. Kosaji (U)	Minakuchi-bashi	29.5	0.0	70.0	0.0	0.0	0.5		1.500
(M)		19.0	0.0	79.0	0.0	0.0	2.0		
(L)		42.0	1.0	57.0	0.0	0.0	0.0		
(B)		12.0	0.0	88.0	0.0	0.0	0.0		
53. Kosaji	Kosaji	1.5	0.0	91.0	0.5	6.0	1.0		
54. Kosaji	Fukawa	30.0	0.0	70.0	0.0	0.0	0.0		
55. Iwamuro	Kitasunagawa	61.0	15.0	20.0	0.0	4.0	0.0		
56. Iwamuro	Iwamuro	36.0	16.5	22.5	0.0	25.0	0.0		1.505
57. Hozoin II	Nonodani	58.5	0.0	36.0	2.0	0.5	3.0		
58. Hozoin II	Hiedani	3.0	0.0	21.5	22.5	0.0	53.0		1.497
59. Hozoin II	Oki	9.0	0.0	16.0	1.0	0.0	74.0	N	
60. Hozoin I	Oki	29.0	0.0	67.0	3.0	0.5	0.5		1.500
61. Sagami	Kamikomazuki	76.0	0.0	20.0	0.0	3.0	1.0		
62. Sagami	Sajigawa	62.0	5.0	24.0	0.0	9.0	0.0		
63. Sagami (L)	Sagami	78.5	0.0	13.0	0.0	8.5	0.0	N	1.500
(B)		83.5	0.0	5.5	0.0	9.0	2.0		1.501
64. Sagami (U)	Kami	76.0	0.0	19.0	0.0	4.0	1.0		1.501
(M)		83.0	0.0	10.0	0.0	5.5	1.5		
(L)		93.5	0.0	4.0	0.0	1.5	1.0		
(B)		89.0	0.0	2.5	0.0	5.5	3.0		1.501
65. Iso	Kaigake	9.0	0.0	43.0	29.0	0.0	19.0		
66. Masugi	Kitasunagawa	0.5	0.0	3.5	90.0	2.0	4.0		
67. Masugi ?	Tongu-Dam	(1)							
68. Masugi	Kami	2.5	0.0	12.0	80.5	0.0	5.0		
69. Masugi	Terasho	0.0	0.0	1.5	95.0	0.5	3.0		
70. Masugi	Ikeda	0.0	0.0	5.0	79.0	6.0	10.0		
71. Masugi	Mobira	1.0	0.0	2.0	89.0	2.0	6.0		1.495
72. Masugi	Wata	0.5	0.0	4.0	82.0	0.5	13.0		
73. Masugi	Kamimasugi	2.5	0.0	3.0	88.0	4.5	2.0		1.496
74. Ichiuno	Tongu-Dam	(1)	(18)			(19)			
75. Ichiuno	Kami	57.0	38.0	5.0	0.0	0.0	0.0		1.503

name of volcanic ashes	locality	heavy mineral (%) oPx	cPx	Am	Bi	Ap	Zr	NRM	index of glassses
76. Ichiuno	Ichiuno	(32)	(4)	(10)		(8)		N	1.503
77. Yubune	Mobira	4.0	0.0	87.0	2.0	1.0	6.0		
78. Yubune	Wata	14.5	2.5	66.0	0.0	15.5	1.5		1.505
79. Yubune	Yamade			(8)	(3)	(1)			
80. Yubune	Gotanda	23.0	0.0	60.0	3.0	12.0	2.0		
81. Sunagawa	Kitasunagawa	9.0	0.0	83.0	0.0	7.0	1.0		
82. Sunagawa ?	Ruôike	(3)	(17)		(9)				

Table 2. Heavy mineral composition and refractive index of glasses of the volcanic ash layers in the Kobiwako group. (The marks are shown in Table 1)
*: the sample number reported by YOKOYAMA & KUSUKI (1969);
(U): upper part, (M): middle part, (L): lower part, (B): basal part,
(15): numbers of crystals.

- Kohoku district -
Shiratsuchidani, *Doken-yama*, *Akatsuki* and so on.
- Kosei district -
Pink, *Yamada*, *Azuki*, *Biotite*, *Hacchoike* II, *Sakara* and *Minamisho*.
- Konan district -
Nango I-VI and *Ishiyama* I, II.
- Koto district -
Makiyama, *Sunagawa*, *Yubune*, *Ichiuno*, *Masugi*, *Iso* I, II, *Sagami*, *Hozoin* I, II, *Iwamuro*, *Kosaji*, *Kamide*, *Kaigake*, *Naiki* I, II, III, *Hazama*, *Mushono* (*Pumice*), *Kono* I, II, III, *Hara*, *Ikenowaki*, *Naka*, and *Kitawaki* I, II.

A part of these volcanic layers has been described by several authors (TAKAYA, 1963; YOKOYAMA, 1967; YOKOYAMA *et al.*, 1968 and KAIGAKE RESEARCH GROUP, 1969 MS),

1. Volcanic ash layers of the Kohoku area.

The tephrochronology of the Kohoku area has not been established yet. Some outcrops of volcanic ash layers are discovered and these beds are named the *Shiratsuchidani*, *Doken-yama* and *Akatsuki* etc.. The *Shiratsuchidani* volcanic ash bed lies in a thick coaly clay and made of is white, medium-grained volcanic ash. It is seen at two places, Shiratsuchidani and Kawaguchi, Takashimacho. The thickness is 300-500 cm. Under the microscope, glass is abundant and biotite and hornblende are also found. Refractive index of glasses is 1.499.

The *Doken-yama* volcanic ash layer is exposed at a single locality near the Doken-yama, Aibano, Takashima-cho. It is 40cm thick and is composed of medium-grained volcanic ash. The color is yellowish white. Glass is dominant and orthorombic pyroxene, biotite and hornblende are also found. Refractive index of glasses is 1.498.

The *Akatsuki* volcanic ash layer is found at adjacent two places. It will be a good key bed, for it has a characteristic succession; that is, fine-grained, white upper part, about 20cm thick and coarse-grained, pumiceous lower part containing many hornblende crystals which can be distinguished by a naked eye. The thickness of the lower part is about 5cm.

Other volcanic ashes are exposed at several places, but they are not traceable by lacking conspicuous character.

2. Volcanic ash layers of Kosei area.

a. *Sakura*, *Hacchoike* II, *Azuki* and *Yamada* volcanic ash layers

These beds, which are good key beds in the Osaka group, are also found in the Kobiwako group. The internal succession and mineral composition are similar to those in the Osaka group, so, detailed description is not given here. The outcrops and the thicknesses are shown in Table 3.

Name	Location of outcrops	Thickness	NRM
Sakura	many places near Kurihara, Shimoryuge, Minamisho and Kamiogi	0-60 cm.	N
Hacchoike II	one place, south of Kamiogi	7 cm.	
Azuki	three places along the River Kisengawa	20-300 cm.	R
Yamada	one place along the River Kisengawa	0-5 cm.	

Table 3. Volcanic ash layers of the Kobiwako group in Kosei area except the Minamisho, Biotite and Pink volcanic ash layers.

b. *Minamisho* volcanic ash layer

Type locality: south of Minamisho, Katata-cho, Shiga Prefecture.

Thickness: 0-20cm.

Type of glass: B and C.

This bed is observed at only three places near Minamisho forming patches in a clay bed. The horizon is 10-20m below the *Sakura* volcanic ash layer. This white, medium-grained volcanic ash contains rich glass, common quartz and hornblende with rare apatite and orthorombic pyroxene.

c. *Biotite* volcanic ash layer (ISHIDA and YOKOYAMA, 1969; the *Sakawa* Tuff by TAKAYA, 1963)

Type locality: Sakawa, Shiga-gun, in Shiga Prefecture.

Thickness: 2-7cm.

NRM: reversed polarity.

"This has been recognized only at Katata hill, … pure white, fine-grained tuff with a thin basal seam containing much biotite crystals. Average thickness of 2-4 cm and the biotite bearing basal seam is 0.5 cm. The continuity is comparatively good in spite of its small thickness. (TAKAYA, 1963)".

The basal part rich in biotite is 4cm in maximum thickness, and the largest biotite crystals reach 3mm in diameter. Besides biotite, apatite, orthorombic pyroxene and hornblende are commonly observed under the microscope.

d. *Pink* volcanic ash layer (the *Oono* Tuff in the west side of the Lake Biwa by TAKAYA, 1963)

Type locality: Senriyama hill in Osaka Prefecture (Osaka group). A representative outcrop in this group is at Sakawa, Katata-cho, Shiga Prefecture.

Thickness: about 30 cm.

NRM: normal polarity.

Type of glass: Aab and Ba.

The internal succession is quite similar to that in the Osaka group. Hornblende and orthorombic pyroxene are dominant, but zircon, biotite and clinopyroxene are rather rare.

3. Volcanic ash layers of the Konan area.

a. The volcanic ash layers at Nango region.

At Nango in Otsu City, there are several exposures of volcanic ashes in six horizons. The lowest two ash beds were discovered at the bottom of the Seta River when the dam (Nango-Araizeki) was under construction (NAKAZAWA and ISHIDA, 1965), but now they are invisible. The specimens contain certain species of orthorombic pyroxene and hornblende.

	locality	thickness	color	name
VI	Akao, east of Nango	40 cm	grey white	
V	south west of Nango	5-15 cm	pinkish white	
IV	south west of Nango	50 cm	yellowish grey	(Pumice)
III	south of Nango	7-10 cm	pinkish white	

Table 4. Volcanic ash layers in Nango region

The other volcanic ash beds of this area are listed in Table 4.

b. The volcanic ash layers at Zeze region.

Three volcanic ash layers were recognized during the field survey of this area (NISHIYAMA RESEARCH GROUP, 1969 MS). The layers have been weathered very much. The upper one, 30-40cm in thickness, is white volcanic ash, partly pinkish in color. Most probably, it is the equivalent of the *Sakura* volcanic ash layer.

The middle layer that lies 15m below the upper one is a white volcanic ash bed of 5cm in thickness. The lower layer is a very thin, 1 to 2cm in thickness, intercalated in a sandy facies, 30m below the middle ash layer. Seemingly it is representing the *Hacchoike* volcanic ash layer.

4. Volcanic ash layers of the Kôtô area.

a. *Kitawaki* volcanic ash layer

Type locality: Karigataniike, Kitawaki, Hino-cho in Shiga Prefecture.

Thickness: 100-400cm.

NRM: reversed polarity.

Type of glass: Aaa and Ba.

This pinkish grey volcanic ash is composed of glass flakes with a little amount of heavy minerals, but the lowest part, about 40cm thick, contains many hornblende crystals. Orthorombic and clinopyroxene, biotite and apatite are also found.

b. *Naka* volcanic ash layer. (ISHIDA and YOKOYAMA, 1969)

Type locality: south of Naka, Yokaichi City, in Shiga Prefecture.

Thickness: 40-50cm.

NRM: normal polarity.

Type of glass: A, B and rare C.

This is a yellowish white, fine-grained volcanic bed. The full succession at the type locality is as follows:

a. 10cm, very fine-grained, pinkish white upper part,

b. 10cm, medium-grained, yellowish brown middle part bearing many white small pumices,

c. 20-30 cm, fine-grained, yellowish white lower part.

Orthorombic pyroxene and hornblende are rich in heavy mineral composition. Refractive index of glasses is 1.498.

c. *Ikenowaki* volcanic ash layer (TAKAYA, 1963)

Type locality: Ikenowaki, Eigenji-cho in Shiga Prefecture.

Thickness: 20-80cm.

NRM: normal polarity.

Type of glass: C.

"This tuff is regarded as a useful key bed, having a somewhat remarkable physical appearence and wide distribution. It consists of the pinkish brown, clayey upper part and the pale brown, pumiceous, coarse-grained lower part with remarkable dark brown spots. Under the microscope, very abundant glass fragments, rare quartz, feldspar and hornblende are found. (TAKAYA, 1963)."

Glass and feldspar have many small holes on the surface of grains.

d. *Hara* volcanic ash layer (TAKAYA, 1963)

Type locality: Hara, Hino-cho, in Shiga Prefecture.

Thickness: 30-50cm.

NRM: reversed polarity.

Type of glass: A.

"This homogeneous white tuff is not continuous and has no peculiar physical appearance. But the weathered parts occasionally show pinkish color, which is the only mark. Abundant glass, common quartz, rare feldspar and hyperthene are found. (TAKAYA, 1963)"

The internal succession at the type locality is as follows:

a. 2-3cm, pinkish white, muddy laminated top part.
b. 20cm, medium-grained, white upper part.
c. 1-0.5cm, fine-grained, blue hard part.
d. 5-6cm, coarse-grained, pinkish white part.

Heavy minerals are composed of a little amount of hornblende and dominant hyperthene. Refractive index of glasses is 1.502.

e. *Kono* III volcanic ash layer (*Kono* tuff of TAKAYA, 1963)

Type locality: south of Kono, Hino-cho, in Shiga Prefecture.
Thickness: 30-70cm.
Type of glass: A.

The TAKAYA's description is rewritten here with in the following lines. "Not so continuous but has a rather distinct physical appearance as follows: 15cm brown clayey top part, 10cm brownish grey, finely stratified middle part and 10cm reddish brown coarse-grained basal part. The ratio of the three parts is variable but the brownish color is a good mark throughout the entire layer. The average thickness is 40cm at Hino hill, but it decreases rapidly towards the west. By this reason of the area, it is difficult to pursue this key bed on the further side. The components of the basal part recognized under the microscope are as follows: fresh or half devitrified glass is common; quartz and hornblende are also found in some degree : pyroxene is scarce."

The middle and basal parts have many small pumices which are brown in color. Orthorombic pyroxene and hornblende are relatively dominant. Zircon is contained in a small quantity only.

f. *Kono* II volcanic ash layer (ISHIDA and YOKOYAMA, 1969)

Type locality: north of Nishioji, Hino-cho in Shiga Prefecture.
Thickness: 20cm.
NRM: normal polarity.
Type of glass: C.

The normal polarity obtained from this volcanic bed is correlated with the Oludovei events of the Matuyama Reversed Epoch, that is, Plio-Pleistocene boundary (ISHIDA, MAENAKA and YOKOYAMA, 1969), This is a homogeneous white bed, composed of medium-grained volcanic materials, but it becomes yellow when weathered. Colored minerals are mostly amphibole, most of which are green hornblende with a little amount of brown hornblende. Quartz is rich and glass is rare.

g. *Kono* I volcanic ash layer (ISHIDA and YOKOYAMA, 1969)

Type locality: north of Nishioji, Hino-cho in Shiga Prefecture.

Thickness: 5-10cm.

Type of glass: B and C.

This less important ash bed is white or pink, fine-grained, and thin. Hornblende is rich, while orthorombic pyroxene, biotite, apatite and zircon are scarce among the heavy mineral extracts. Glass is dominant in the light minerals; quartz and feldspar are small in number.

h. *Sakuradani* volcanic ash layer

Type locality: the upper reaches of the Sakuragawa, Hino-cho in Shiga Prefecture.

Thickness: 120-150cm.

This volcanic layer is divided into two parts; the 3-5cm lower part, and the 120-150cm upper part. The appearance of the lower part is similar to that of the *Kasuri* volcanic ash bed. Crystals of hornblende and small pumices are seen by naked eye. The upper part is composed of fine-grained, laminated, yellowish grey colored volcanic ash. Orthorombic pyroxene and hornblende are dominant; biotite, zircon and magnetite are less frequent.

i. *Mushono* (*Pumice*) volcanic ash layer (TAKAYA, 1963)

Type locality: Mushono, Minakuchi-cho in Shiga Prefecture.

Thickness: 100-900cm.

NRM: reversed polarity.

Type of glasses: A and B.

This is the best key bed of all volcanic ashes in the Plio-Pleistonene series in Kinki and Tokai districts, because of not only its great thickness and continuity but also of its characteristic succession. The full succession is as follows:

a. 50-300cm, muddy upper part.

b. 200-400cm, coarse-grained homogeneous middle part containing many large pumices (max. 10cm in diameter).

c. about 100cm, fine-grained, especially well laminated or bedded lower part which consists of pinkish and white layers.

d. 1-3cm, medium-grained basal part which contains many crystals of hornblende.

Such large grains of pumice do not occur in other volcainc ash layers of the Plio-Pleistocene series in Kinki district.

Heavy minerals are scarce in the lower and middle parts; they are biotite, hornblende, orthorombic pyroxene, zircon, clinopyroxene etc.. Refractive indices of glasses ranges from 1.497 to 1.502.

j. *Komazuki* volcanic ash layer (YOKOYAMA *et al.*, 1968)

Type locality: Kamikomazuki, Hino-cho in Shiga Prefecture.

Thickness: about 50cm.

NRM: reversed polarity.

Type of glass: Ba and rare A.

The full succession is as follows:

a. 20-25cm, medium-grained, grey upper part.
b. 4cm, very fine-grained laminated middle part.
c. 15-25cm, hard fine-grained pinkish, lower part.
d. 1-2cm, coarse-grained, white basal part.

In the lower pink part, white ash-balls of 5-10cm in diamater are scattered irregularly. It is a very good key bed because of its continuity and remarkable appearance. Orthorombic pyroxene and hornblende are dominant and clinopyroxene is rare in proportion. Refractive index of glass is 1.504.

k. *Hazama* volcanic ash layer

Type locality: Hazama, Hino-cho in Shiga Prefecture.

Thickness: 20-50cm.

Type of glass: A.

This is divided into three parts:

a. about 10cm, fine-grained, muddy upper part.
b. 5-15cm, fine-grained, laminated hard part.
c. 15-20cm, coarse-grained, white sandy basal part.

Mostly it is made of glasses, and seldom contains heavy minerals. Apatite, zircon and hornblende are seen under the microscope. Refractive index of glass is 1.498.

l. *Naiki* II volcanic ash layer (YOKOYAMA *et al.*, 1968)

Type locality : Naiki, Minakuchi-cho in Shiga Prefecture.

Thickness: about 30cm.

This homogeneous pinkish bed consists of medium-grained volcanic sands. It is a good key bed because of its continuity and the chractaristic composition of heavy minerals being very dominant in small hyperthenes.

m. *Kaigake* volcanic ash layer

Type locality: west of Kaigake, Hino-cho in Shiga Prefecture.

Thickness: more than 100cm.

This bed is mainly made of white or grey volcanic sands containing a little amount of pumice grains smaller than 2cm in diameter. As the extension is limited to small area, it is not a useful key bed.

n. *Kamide* volcanic ash layer (YOKOYAMA *et al.*, 1968)

Type locality: Kamide, Kôga-cho in Shiga Prefecture.

Thickness: 5-10cm.

Type of glass: B and C.

This is divided into two parts: about 5cm coarse-grained pumiceous lower part and about 10cm medium-grained upper part. The upper part is often absent. Large biotites in the lower part are visible by the naked eye. It also contains other heavy minerals : orthorombic and clino-pyroxenes, hornblende and zircon. Refractive index of glass is 1.496.

o. *Kosaji* volcanic ash layer (TAKAYA, 1963)

Type locality: Nishide, Kôga-cho in Shiga Prefecture.

Thickness: 20-50cm.

NRM: normal polarity.

Type of glass: dominant B and rare A, C.

TAKAYA (1963) told "Well continuous, consisting of three layers; 10cm yellowish grey, fine-grained top layer, 5cm purplish grey, fine-grained middle part and 25cm purplish grey coarse-grained basal part. In particular the thick basal layer is marked with dark brown spots, which are very useful for a key."

YOKOYAMA *et al*, (1968) recognized one more graded cycle below the Takaya's succession, that is, the layer is composed of two cycles. The lower cycle is mainly composed of coarse-grained glasses containing predominant colored minerals, in which orthorombic pyroxene and hornblende are involved.

Index of glass is 1.500.

p. *Iwamuro* volcanic ash layer (YOKOYAMA *et al.*, 1968)

Type locality: south of Iwamuro, Kôga-cho in Shiga Prefecture.

Thickness: 0-7cm.

This brownish grey sandy ash bed is situated at 6-7 m above the *Hozoin* volcanic ash layer in the same clay bed. Sometimes it becomes a chain of small balls lying on a horizontal plane. It is composed mainly of volcanic glasses with orthorombic, clino-pyroxenes, apatite and hornblende. Refractive index of glass is 1.505.

q. *Hozoin* I, II volcanic ash layer (TAKAYA, 1963)

Type locality: Oki, Kônan-cho in Shiga Prefecture.

Thickness: I, about 5cm and II, about 20cm.

NRM: normal polarity.

These two volcanic seams occur side by side always at 60-80cm intervals in a thick clay bed (the Iwamuro Clay Member). As this charactaristic occurrence seldom varies laterally, the pair offers the best marker in Omi-Iga Basin with a nickname "avec" in the field. Both of I and II consist of medium-grained grey volcanic sands, glasses, and become to yellow in color when weathered. Hornblende and zircon are common among the heavy minerals. Refractive indices of glasses is as follows: I, 1.500 and II, 1.497.

r. *Sagami* volcanic ash layer (IKEBE, 1934, YOKOYAMA *et al.*, 1968)

Type locality: Sagami, Kôga-cho in Shiga Prefecture.

Thickness: 10-20cm.

NRM: normal polarity.

Type of glass : dominant A and common B, C.

The full succession is as follows:

a. 5cm, brownish grey, fine-grained upper part.

b. 7cm, yellowish grey medium-grained part.

c. 2-3cm, greyish white basal part having a graded pattern.

This is extensively continuous being intercalated in the thick clay (the Nojili Clay Member). It is a very competent key bed because of its remarkable features of basal part and dominant hyperthene in heavy mineral composition. In addition to hyperthene, hornblende and apatite are always seen under the microscope.

Idiomorphic hyperthenes are often wrapped by glasses. Refractive index of glasses is 1.501.

s. *Iso* I, II volcanic ash layers (YOKOYAMA *et al.*, 1968)

Type locality: Shimo-Iso, Kônan-cho in Shiga Prefecture.

Thickness: 5-10cm.

They are fine-grained white ash beds found in thin lenticular coaly clay bed and are rather discontinuous. Orthorombic pyroxene, hornblende, biotite and zircon are contained in the heavy minerals.

t. *Masugi* volcanic ash layer (YOKOYAMA *et al.*, 1968)

Type locality: the pass between Kamimasugi and Higashiyubune, boundary location of Mié and Shiga Prefecture.

Thickness: 20-50cm.

The lower fine-grained part is dark grey in color and consists of volcanic glass grains. The upper coarse-grained part, about 20-50cm thick, is grey or bluish grey on fresh outcrops, but it becomes yellowish green by weathering. This part is composed of crystalline grains such as quartz, biotite, hornblende with glasses and pumices.

TAKAYA (1963) said "This is the only crystalline dacite tuff found in the Paleo-Biwa (Kobiwako) group, and one of the most useful key bed."

Refractive index of glass is 1.495.

u. *Ichiuno* volcanic ash layer (IKEBE, 1934)

Type locality: Ichiuno, Kôga-cho in Shiga Prefecture.

Thickness: about 5cm.

NRM: normal polarity.

This is a dark green hard volcanic ash bed which becomes white or yellowish white in color when weathered, and is an useful key bed. Pyroxene, hornblende and apatite are seen in heavy minerals. Refractive index of glass is 1.503.

v. *Yubune* volcanic ash layer (TAKAYA, 1963)

Type locality: Higashiyubune, Ayama-mura in Mié Prefecture.

Thickness: 50-100cm.

This is always composed of alternations of 5cm fine-grained part and 10-20cm coarse-grained part. White small pumices, about 1mm in diameter are often seen in the coarse part. The color of the fresh part is dark green, while pale green or yellow in weathered part. TAKAYA (1963) described it as follows; "This is so characteristic that it has the popular local name of Nuka. It is widely continuous, and the lateral change is slight owing to its intercalation in thick clay. The fine-grained part is yellowish grey in color and has a peculiar appearance on the weathered outcrops. That is, many cracks develop crosswise on the weathered surface, and along the cracks a lot of small (about 1 cm^3) cubic fragments are splintered off and piled up around the foot of the outcrops. The local name Nuka has derived from these phenomena. The coarse-grained part is grey in color and homogeneous in lithofacies."

This contains hornblende, apatite and orthorombic pyroxene as heavy minerals. Refractive index of glass is 1.505.

w. *Sunagawa* volcanic ash layer

Type locality: River Kitasunagawa, east of Kaigake, Hino-cho in Shiga Prefecture.

Thickness: about 50cm.

This is found at two places: type locality and Nishikaigakedame, northeast of Komazuki. It consists of yellowish medium-grained ash. Hornblende, orthorombic pyroxene and apatite are involved in the abundant glasses and small pumices. Both appearance and composition are quite similar to the *Yubune* volcanic ash layer.

x. *Makiyama* volcanic ash layer

Type locality : Makiyama, Ayama-mura in Mié Prefecture.

Thickness: about 5cm.

This white, very fine-grained ash bed is intercalated in a coaly clay bed and is well continuous in Ayama area.

5. Correlation of four areas, Kohoku, Kosei, Konan and Kotô districts.

TAKAYA (1963) mentioned that the *Kitawaki* volcanic ash layer is the same as the *Pink* of the Osaka group. But these two are clearly distinguished by heavy mineral composition and shape of glasses, etc.. The *Oono* tuff in the Kosei area is the same as the *Pink* volcanic ash layer because the features are identical to those of the *Pink* in the Osaka group. But the *Oono* tuff in Kotô area, which is called the *Kitawaki* volcanic ash layer in recent years, is lower in horizon than the *Pink*, and may correspond to the *Kamimura* volcanic ash layer.

A few volcanic layers were discovered in the Konan district in this year (Table 5). NAKAZAWA and ISHIDA (1965) found two volcanic ash layers in basement of the dam of the River Seta at Nango ("Nango-Araizeki"). These two are similar to the *Naiki* volcanic ash. The volcanic ash layers exposed at the south of Nango correspond to the *Pumice* volcanic ash layer in the Kobiwako, Tokai and Osaka groups. We have not any informations for the correlation between the Kohoku and the other area.

The correlation of four area is shown in Fig. 5.

5) Volcanic ash layers of the Tokai group.

horizon	name	site-number	locality	heavy mineral composition (%) oPx	cPx	Am	Bi	Ap	Zr	index of glass
Oizumi formation	Kamiaiba	A-174	Kamiaiba	18.5	3.0	20.5	51.0	0.5	6.5	......
	KomenoIII	A- 29	Komeno							1.501
	Komeno II	A- 27	Komeno							1.498
	Komeno I	A- 23	Komeno	30.0	1.8	34.5	20.0	6.4	7.3	1.498
	Komeno I?	A-131	Hatage	31.5	3.5	56.5	7.0	0.5	1.0	
	Sakura-dani (Ho)	A- 49	Kanae	0.0	0.0	86.0	1.5	12.0	0.5	
		A- 86	Higashitani	3.0	0.0	90.0	0.5	6.5	0.0	
		A- 54	Kanae	11.5	4.0	80.5	0.0	3.0	1.0	
		A-186	Kawahara	0.0	0.0	89.5	3.5	7.0	0.0	
	Hy	A- 46	Shimogumi	82.5	4.0	0.5	0.0	12.5	0.5	
		A- 55	Kanae	87.0	3.0	6.0	0.0	2.5	1.5	
		A-183	Kawahara	73.5	0.0	18.0	1.0	7.5	0.0	
	Pumice	A- 36	Sejihara	60.0	1.6	28.0	3.3	0.0	7.1	1.498
		A-135	Sejihara	45.9	1.4	42.2	9.1	0.0	1.4	
		A-182	Kawahara	60.9	1.8	26.1	5.0	0.6	5.6	
Kono formation	Kawahara	A-142	Obara-isshiki	4.0	0.0	9.0	84.0	2.0	1.0	
		A-268	Ichinohara	2.7	0.0	8.3	70.0	9.0	10.0	1.495

Table 5. Heavy mineral composition and index of glass flakes of the volcanic ashes of the Age sub-group. (Marks are shown in Tables 1. and 2.)

The volcanic ashes of this group are quite similar to those of the Kobiwako group except a few in the lowest part. The *Yubune*, *Ichiuno*, *Masugi*, *Sagami*, *Kaigake*, *Mushono* (*Pumice*), *Sakuradani* etc. are also discovered in the Tokai group. In the lower horizon than the *Yubune*, a very thick volcanic layer (maximum 17m) is found at the south of Tsu City and the east of Nagoya City. This is composed mainly of fine- or medium-grained volcanic ash, and contains a small quantity of heavy minerals. The color is white or yellowish grey, and refractive index of glass is 1.496.

The features of the volcanic ashes of the Tokai group are summarized in Table 5.

6) The correlation of the three groups, the Osaka, Kobiwako and Tokai.

The correlation of the Plio-Peistocene series in Kinki and Tokai district has been carried out by means of tephra and fossils combined. In addition, paleomagnetic polarity changes are also efficient. The outline was already presented by the writer and others (ISHIDA and YOKOYAMA, 1969, and ISHIDA, MAENAKA and YOKOYAMA, 1969). The present informations about the correlation of three basins are shown in Fig. 3. The paleomagnetic polarity, *Metasequoia* flora, fossil elephants and several volcanic ash layers such as the *Sakura, Azuki, Pink, Pumice, Masugi, Ichiuno* and *Yubune* are good aim for the correlation.

7) Relation between tephra and horizons of fossils.

The horizons of fossils can be exactly determined by volcanic ash layers.

A. Mammals (Fig. 22)

Stegodon elephantoides is at the horizon of the *Yubune* volcanic ash. This species is known also in the lower part of the Irrawaddy Series in Burma.

Stegodon akashiensis is in the horizons between the *Kamimura* and the *Pink* volcanic ash layers (IKEBE *et al.*, 1966). But it is also found from the horizon which is considered to be lower than the *Pumice* volcanic ash layer at Nishimomokawa in Awajishima island (ISHIDA *et al.*, 1969).

Elephas shigensis is discovered in the horizons between the *Yellow* and *Hacchoike* (Ma 5) volcanic ash layers. It has been thought that this species lived in the early Pleistocene.

Stegodon orientalis is found from the horizon of Ma6 and the *Sakura* volcanic ash layer. This is a typical species of the Wanhsien fauna in China.

B. Plants (remains)

a. *Pinus trifolia* flora (MIKI, 1941, 1963, 1965) occurs in the Seto ceramic clay bed. It is composed of 116 species, 70 species of which are now extinct in Japan.

b. The lowest part of the Osaka group nearly equivalent to the horizon between the *Kaigake* and *Kosaji* volcanic ashes yields fair Tertiary type plants in Sennan area, southern part of Osaka Prefecture (MIKI, 1948; ITIHARA, 1961). This flora does not have *Pinus trifolia, Sequoiadendoron* and *Carya*, etc., but implies *Ginkgo* and *Taiwania*, etc. ITIHARA (1961) named this age "the age of flourish of *Metasequoia* flora".

c. *Picea polita, Abies, Pinus koraiensis* and *Metasequoia* are found from beds about 10m below the *Kamimura* volcanic ash in the northern part of Ibaraki City. In the same area, *Picea maximowiczii, Iris* and *Menyanthes trifoliata* occured at the horizon about 10m above the *Kamimura* volcanic ash (IBARAKI RESEARCH GROUP, 1966). The former represents the Ibaraki I cold age and the latter the Ibaraki II cold age (ISHIDA *et al.*, 1969). The higher horizons than the *Menyanthes* bed yields abundant *Metasequoia*, and still contains *Cunnighamia* and *Pterocarya paliurus* etc. However, the Tertiary type plants gradually decrease

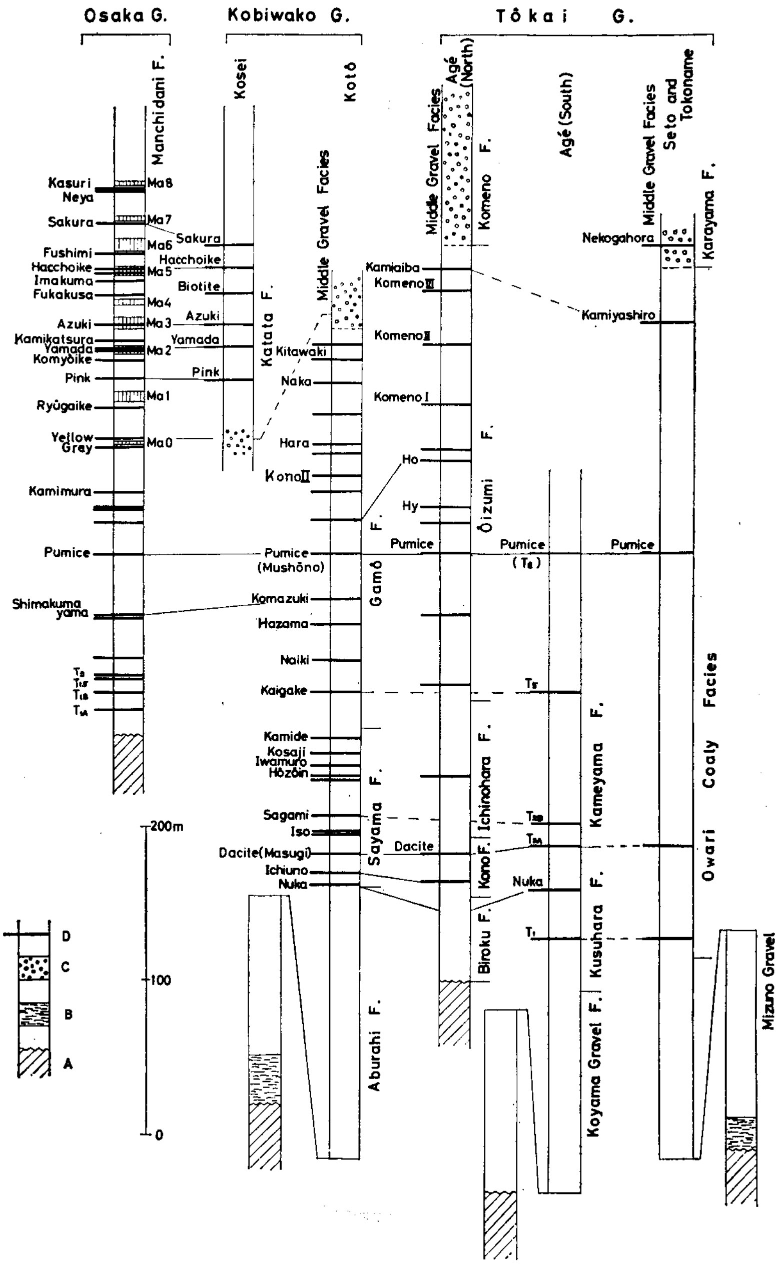


Fig. 3. Tephrochronology and correlation of the three groups, the Osaka, Kobiwako and Tokai groups.
A: basements, B: ceramic clay, C: middle gravels, D: volcanic ash layer.

in number above the *Kamimura* volcanic ash layer. ITIHARA (1961) called this age "the age of extinction of *Metasequoia* flora".
d. ITIHARA (1961) obtained *Menyanthes trifoliata* in the bed just below the *Azuki* volcanic ash layer, the most useful key bed of the Osaka group, at Goken-ya, west of Tondabayashi. ISHIDA *et al.* (1969) named this age "the Goken-ya cold age". *Metasequoia* was probably extinguished in this time from the Kinki area.
e. "The conifer age at Manjidani (MIKI, 1941)" is charactarized by many cold plants, *Abies veitchii, Larix gmelinii, Picea bicolar, Pinus koraiensis, Betula platyphylla, Acer* cf. *miyabei, Menyanthes trifoliata* and *Oxycoccus palustris.*

These cold plants are also discovered at the same horizon in Hirakata hill (ITIHARA *et al.*, 1966). This is called "the Manchidani cold age" (ISHIDA *et al.*, 1969).
f. Ma7 yields a warm plant, *Ruppia* and Ma8 contains many warm plants, *Neolitsea aciculata, Quercus gilva, Q. paucidentata, Sympocos lucida* and *Syzygium buxfiolium* at Shinkori, Hirakata (ITIHARA *et al.*, 1966).

The *Syzygium* bed at Uegahara, Nishinomiya is correlated to Ma8 (ITIHARA *et al.*, 1966), which yields *Podocarpus nagi, Mirica rubra, Quercus glauca, Q. paucidentata, Q. phillyreoides, Cinnamomm doederleinii, Illicium religiosum, Michelıa comoreasa, Distylium racemosum, Camellia sasanqua, Syzygium buxifolium* and *Symplocos primifolia,* etc.

The age of Ma8 was named "the Shinkori warm age" (ISHIDA *et al.*, 1969)
g. *Picea maximowiczii* and *Fagus microcarpa* were reported from a horizon about 50m above Ma8 at Takakuradera, Senpoku (ITIHARA *et al.*, 1966).
C. Pollens
a. SHIMAKURA (1966) reported the *Carya-Nyssa-Liquidambar* pollen flora from the lower part of the Kobiwako and Tokai (Agé subgroup) groups. Rearranging the SHIMAKURA's data (SHIMAKURA, 1965, 1966) by using the volcanic ash layers as time surfaces, it is clarified that fossil *Carya* is obtained limitedly in the lower horizons than the *Yubune* volcanic ash. But *Nyssa* and *Liquidambar* are found from the still upper horizon. The upper limit of *Nyssa* may be the horizon of the *Kosaji* or *Kamide* volcanic ash layers in the Kobiwako group. *Liquidambar* is reported from still higher horizon.
b. The somewhat cold pollen flora is found under the *Masugi* volcanic ash at Terasho, Konan-cho in Shiga Prefecture (NASU 1966). It is called "the Terasho cold age" (ISHIDA *et al.*, 1969).
c. The pollen of the *Metasequoia* are found from the lower horizon than the Gokenya cold age (under Ma3). This accords with the results of the plant remains.
8) Paleomagnetic age-determination of the volcanic ash layers

ISHIDA *et al.* (1969) estimated the abusolute age of the main volcanic ash layers in the Plio-Pleistocene of the Kinki from the relation of the polatity change and the thickness of the sediments, as follows; ***Fukakusa***: 0.69^{-}my, ***Azuki***: 0.80 my, ***Pink***: 0.90 my, ***Yellow***: 1.20 my, ***Naka***: 1.65 my, ***Kono*** **II**: 1.90 my, ***Pumice***: 2.00 my, ***Kaigake***: 2.45^{+}my, ***Dacite*** (***Masugi***): 3.05^{+}my, ***Ichiuno***: 3.10^{+} my, (See, Fig. 22)

STRATIGAPHY OF THE PLIO-PLEISTOCENE SERIES IN KINKI

The stratigraphy of the individual group in different basins was worked out by many authors: ITIHARA *et al.* (1955), ITIHARA (1960), ITIHARA and OGURO (1961), HUZITA (1954), FUKAKUSA RESEARCH GROUP (1962), HARATA *et al.* (1963), TAKAYA and ITIHARA (1964), ITIHARA *et al.* (1966), IBARAKI RESEARCE GROUP (1966), NISHIYAMA RESEARCH GROUP (1967, 1968), NAKAGAWA (1967), TAKETSUZI and ITIHARA (1967) for the Osaka group; IKEBE (1933, 1934), TAKAYA (1963), YOKOYAMA *et al.* (1968), KAIGAKE RESEARCH GROUP (1968, MS) for the Kobiwako group, TAKEHARA (1961, 1966), KATÔ (1957), MATSUI (1942), YOKOYAMA (1966) for the Tokai group.

The stratigraphical columns of the Plio-Pleistocene in Kinki are summarized in Fig. 3. according to the tephrochronological aspect.

1. Stratigraphy of the Osaka group.

The stratigraphy of the Osaka group has already been established by many authors. The columnar sections of some area and the relations among the marine clays, volcanic ashes, lithofacies and each stage mentioned later on, are shown in Fig. 4. and Table 6.

2. Stratigraphy of the Kobiwako group (Fig. 5 and Table 7)

1) Shimagawara formation

This is the ceramic clay facies in the Iga basin and the Kowa highlands. It is mainly composed of arkosic coarse sands and gravels containing some lignites and coaly clays called "Kibushi clay". MIKI (1941) reported the following fossil plants from this formation in Shimagawara-mura, Ayama Gun in Mie Prefecture; namely, *Pinus fujii*, *Glyptostrobus pensilis*, *Metasequoia disticha*, *Sequoia semervirens*, *Alnus japonica*, *Brasenia purpurea*, *Corylus hterophylla*, *Fagus hayatae*, *Cocculus trilobus*, *Stephania japonica*, *Schizandra nigre*, *Hamamelis parrotioides*, *Berchemia racemosa*, *Paliurus nipponicus*, *Vitis* cf. *thunbergii*, *Trapa incisa*, *T. mammillifera*, *Cornus controversa*, *Pieris* sp., *Styrax japonica*, and *S. rugosa*.

2) Iga-Aburahi formation

a. Iga sand and gravel

This is the basal gravels of Plio-Pleistocene series, which is composed chiefly of fluvial gravels. It extends in southeastern part of Iga basin and in the Kowa highlands at Shimagawara-mura. This formation often intercalates seams

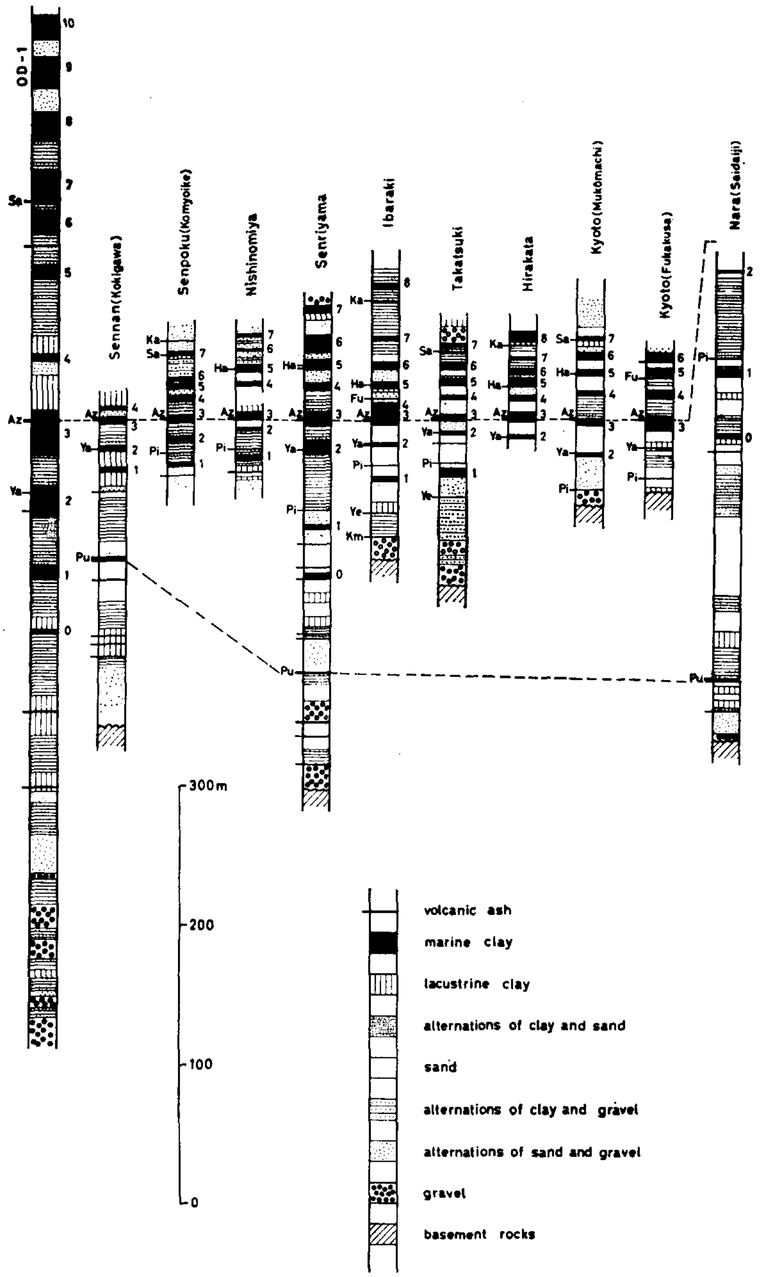


Fig. 4. Columnar sections of the Osaka group. Pu: *Pumice*, Km: *Kamimura*, Ye: *Yellow*, Pi: *Pink*, Ya: *Yamada*, Az: *Azuki*, Fu: *Fukakusa*, Ha: *Hacchoike*, Sa: *Sakura*, Ka: *Kasuri*.

Table 6. Stratigraphy of the Osaka group

my.	stage	marine clays		volcanic ashes	lithofacies
0.3— 0.4—	Manchidani stage	upper most part	Ma 8 — Ma 7 —	—Kasuri —Neya —Sakura	marginal gravels with two thin marine clays
0.7— 0.8—	Hacchoike stage	upper part	Ma 6 — Ma 5 — Ma 4 — Ma 3 —	—Hacchoike —Fukakusa —Azuki	alternations of lacustrine sand and marine clay
0.9— 1.2—	Nara stage	lower part	Ma 2 — Ma 1 — Ma 0 —	—Yamada —Pink —Yellow	alternations of fluvial or lacustrine sand-gravels and lagoonal clay
	Middle gravel stage			—Kamimura	fluvial gravels and lacustrine sands
2.0—	Gamo stage	lowest part		—Pumice	alternations of lacustrine sand and clay
	Sayama stage	*		—Masugi —Yubune	gravels lacustrine clay
	Iga-Aburahi stage				
4.5—	Seto stage				

* shobudani Bed.

of lignite and coaly clay ("Kibushi clay") in marginal regions. The upper part interfingers with the lower part of the Aburahi sands. The follow-ing fossils are reported from this member:

Plants: *Glyptostorobus pensilis, Pterocarya multistriata, Fagus ferruginea, Buxus japonica, Juglans cinerea.*

Mollusc: *Viviparus longispira, Unio biwae, Anodonta* sp..

Table 7. Stratigraphy of the Kobiwako group.

IKEBE (1933)(1934)	TAKAYA (1963)		YOKOYAMA (1968)		my.	stage
Ryuge sands and gravels	B 11	Katata formation	Ryuge sands	Katata formation	—0.4	Manchidani stage
Minamisho clay-bed (150m+)	B 10		Minamisho clays		—0.8	Hacchoike stage
	B 9				—0.9 —1.2	Nara stage
						Middle Gravel stage
	B 8 B 7 B 6		Gamo formation			Gamo stage
	B 5	Koga formation			—2.0	
Sayama formation (250m+)	B 4 B 3 B 2		Sayama formation		—3.0	Sayama stage
Aburahi formation (400m+)	B 1	Iga formation	Aburahi formation			Iga-Aburahi stage
					—4.5	Seto stage

Volcanic ashes		YOKOYAMA (1969)	
—Kasuri —Sakura	Katata formation	Ryuge sands and gravels	Zeze alternations
—Hacchoike —Fukakusa —Azuki		Minamisho clays	
—Pink		Wani sands	Seta gravels II
—Yellow			Zinryo sands
	Yokaichi formation (50m)	Yokaichi gravels	Seta gravels I
—Sakuradani —Mushono	Gamo formation (350m)	Sakuradani sands and clays Hino clays Nunobikiyama sands and gravels	Nango alternations
—Kosaji —Sagami —Masugi —Yubune	Sayama formation (100m)	Kosaji-Iwamuro clays Sunazaka sands Nojiri clays Kazuraki sands and Ichiuno clays Wata clays	
—Makiyama	Iga-Aburahi formation (300m)	Aburahi sands	
		Iga sand and gravels	
	Shimagahara formation (10m+)	C. coaly clays B. sands A. sands and gravels with clays	

b. Aburahi sand

This member is mainly exposed in the western foot-area of Mt. Aburahi (Aburahi-Tsuge area) and Makiyama area.

a) Aburahi-Tsuge area

The lower half is composed of coarse-grained, arkosic sands with thin layers of lignite and gravel. The upper half is composed of medium-grained brown sands at Aburahi area, and it consists of alternations of medium-grained sand and clay in northern Kami-Iwamuro region.

b) Makiyama area

It consists of granitic coarse-grained sand beds with granule and pebble gravels, usually intercalating lignite layers. The matrix is made of white clay. A thin layer of fine-grained white volcanic ash named "*Makiyama* volcanic ash layer" is seen in a coaly clay. This ash layer is so well continuous as to be a good key bed.

3) Sayama formation

YOKOYAMA *et al.* (1968) described the detailed stratigraphy of this formation. It is composed of alternations of thick clay and thin medium-grained sand, except that the Kazuraki Sand Member contains some cobble-pebble gravels. Because outstanding volcanic ash layers are intercalated in these clay facies, the detailed stratigraphical horizons can be determined. The volcanic ash layers are called *Yubune*, *Ichiuno*, *Masugi*, *Iso* I, II, *Sagami*, *Hozoin* I, II, *Iwamuro*, *Kosaji* and *Kamide* volcanic ash layers in ascending order.

This formation is divided into eight members: Wata clay, Iwamuro sand and Kosaji clay members etc. in ascending order.

The lower part below the Kazuraki sands consists of cobble or pebble gravels and coarse-grained sands in Kaigake and Komazuki regions. These gravel-facies, named the Sasaotoge gravels, were deposited at the mouth of the ancient river Yasugawa flowed into the ancient lake Biwa from the Suzuka highland.

The following fossils are obtained from this formation.

Plants: *Metasequoia disticha*··· just above the *Yubune* volcnaic ash
Pinus thunbergii ······Nojiri clay member

Pollen: *Nyssa*, *Keteleeria*, *Metasequoia*, *Liquidamber*, *Pseudolarix* etc.

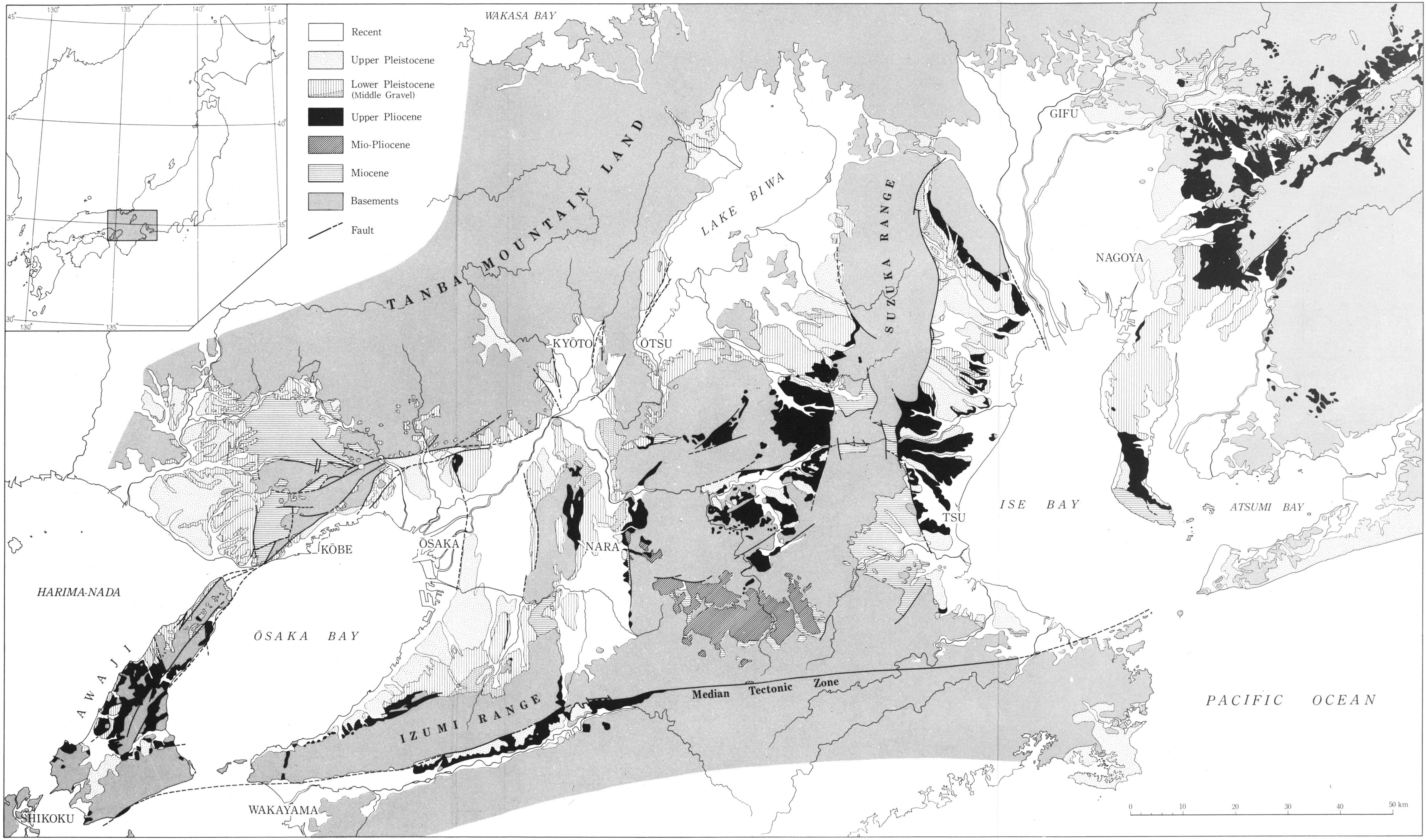
Mollusk: *Anodonta* sp.

4) Gamo formation

It may be divided into three members as follows:

c. alternations of sand and clay (120m±)···Sakuragawa alternation facies
b. clay dominant middle part (150m±)···Hino clay facies
a. sand dominant lower part (100m±)······ Nunobikiyama alternation facies

The Nunobikiyama alternations are well exposed in the Nunobikiyama hills along northern side of the River Yasugawa. Medium-grained, brown sand beds



App. fig. Geologic map of the Plio-Pleistocene series in the eastern Setouchi Geologic Province, by ISHIDA & YOKOYAMA (1969)

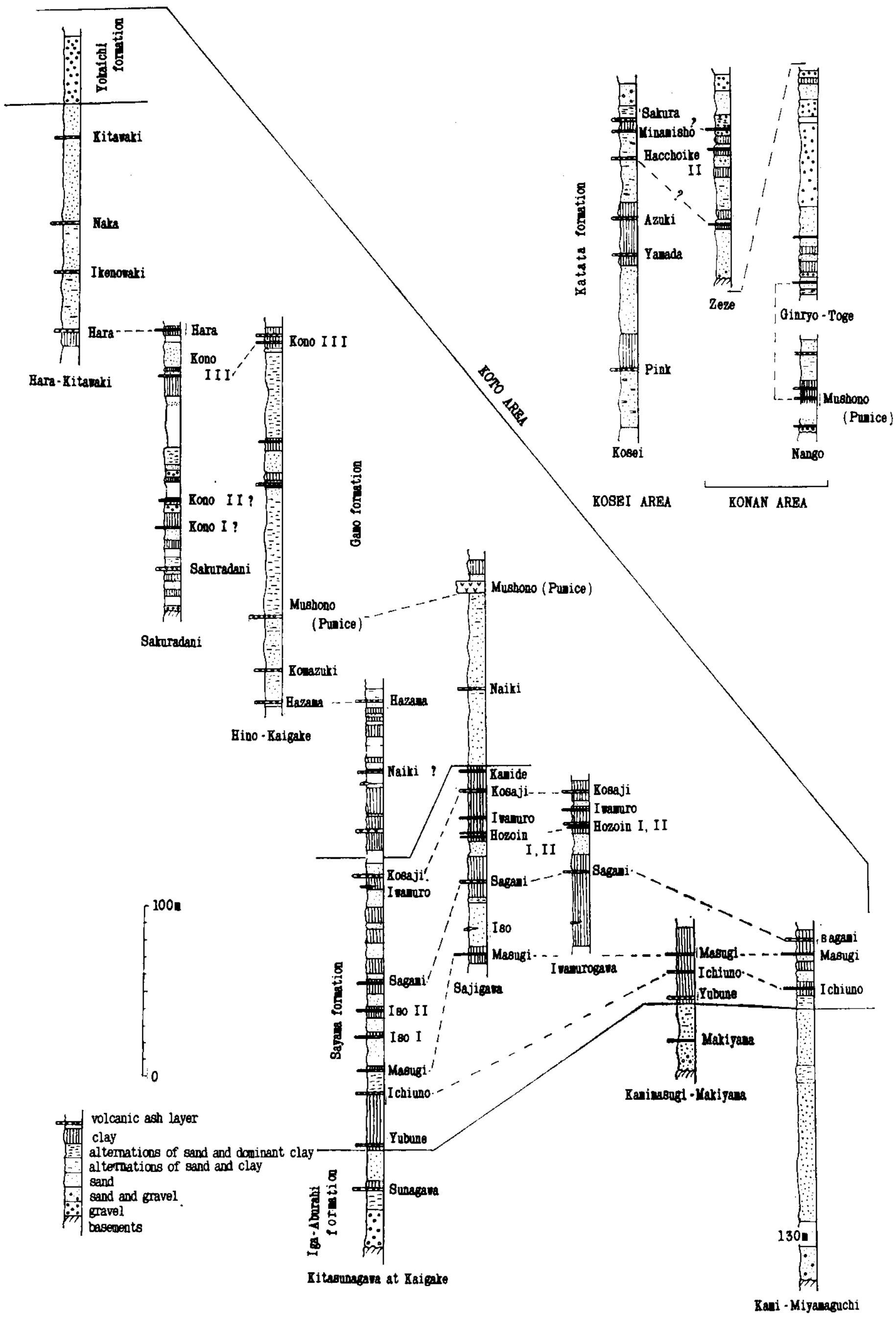


Fig. 5. Columns of the Kobiwako group.

are dominant, and at least five volcanic ash layers are seen in this member. They are called the *Kaigake*, *Naiki*, *Hazama*, *Komazuki* and *Mushono* volcanic ash layers in ascending order.

The Hino clay is composed mostly of massive clay which makes a high cliff along the upper course of the River Sakura. The upper and lowest part contain some fine to medium-grained sand beds. Five outstanding volcanic ash layers are found in this facies: the *Sakuradani*, *Kono* I, II, III, and *Hara* volcanic ash layers in ascending order. MIKI (1948) reported some fossil plants from the bottom of the River Soma, west of Kibukawa, such as, *Sequoia sempervirens*, *Glyptostrobus pensilis*, *Metasequoia disticha* and *Juglans cinerea* var. *megacinerea*.

The Sakuragawa alternations, which are made of sand rich alternations, are exposed in both sides of middle course of the River Sakura. Three traceable volcanic ash layers are found in this member; *Ikenowaki*, *Naka* and *Kitawaki* volcanic ash layers.

HIROSE (1934) reported the following fossils from the Gamo formation (Hirose's Biwako Bed):

Mollusks: *Anodonta lauta*, *Cristaria spatiosa*, *Corbicula sandai*, *Unio* cf. *biwae*, *U.* cf. *reiniana*, *U.* sp., *Viviparus japonica*, *Viviparus* sp.

Plants: *Acer* ? sp., *Betula* sp. *Laurus* sp., *Pinus* sp., *Quercus* sp., *Trapa natanus*, *Zelkowa serrata*.

5) Yokaichi formation (50m±)

Cobble, pebble and granule gravels of chert, sandstone and other Paleozoic rocks are abundant in this formation. Probably the source of these gravels was upheaving Suzuka ranges.

6) Gomo and Katata formations in Seta region (Konan).

These formations in this area are composed of five members, called the Nango alternations, Seta gravels I, Zinryo sands, Seta gravels II and Zeze alternations in asending order. (NISHIYAMA RESEARCH GROUP, 1969 MS).

The Nango alternations is composed of thick, green colored, massive clay and fine to medium-grained sand. It is well exposed on both sides of the River Seta south of Nango and near Ishizue. Four volcanic ash layers are found in this formation at the south of Nango (Table 5). One of them contains many pumice grains, the maximum diameter of which is 3cm. This layer corresponds undoubtedly to the *Mushono* (*Pumice*) volcanic ash layer in Koto area

NAKAZAWA and ISHIDA (1959) obtained some fossil plants: *Stirax* sp. cf. *microcarpa*, *Pterocarya paliurus*, *Stewartia monadlpha*, *Sapium sebiferum* var. *pleistoceaca* from a horizon in the lower part of this member exposed at the bottom of the River Seta. This flora belongs to the *Metasequoia* flora.

The Seta gravels I and II are composed of coarse sands and well rounded cobble and pebble gravels. The matrix of I is generally coarse sand and that of II usually contains clay. It is well observed at the south of the pass between Zinryo and Do.

The Zinryo sands are well exposed in southeastern area of Zinryo. It is composed of coarse to fine-grained sand layers.

The Zeze alternations, about 120m in thickness, are exposed at south of Zeze. The lower part is chiefly fine-grained sands, and the middle part is coarse to medium sands inserted by two massive lacustrine clay beds both about 10m+ in thickness. The upper part is composed of gravels.

7) Katata formation in Kosei area.

a. Wani sands

This is well exposed along the down stream of the River Kisengawa and Wani. It is composed of coarse sand layers and is at least 150m in thickness.

b. Minamisho clays.

The Minamisho clay member, being a bed of alternating predominant lacustrine clays and less developed sands, covers the Wani sand. The *Azuki* volcanic ash layer, the most efficient key bed of the Plio-Pleistocene series of Kinki lies in the basal part of this member. Other volcanic ash layers, *Hacchoike*, *Biotite*, *Minamisho* and *Sakura*, are also found in this member.

Fossils reported are as follows:

IKEBE (1933) : plants: *Fagus microcarpa*, *F. crenata*, *F. japonica* ?, *Zelkowa* sp., *Trapa macropoda*, *Phragmites* sp.. mollusk: *Lanceolaria oxyrhyncha*, *Unio douglasiae nipponensis*, *Unio bewae*, *Unio* ? sp., *Inversidens brandti*, *I. hirasei*, *I. japanensis*, *I. reiniana*, *Cristaria plicata*, *Anodonta* ? sp., *Corbicula* sp., *Semisulcospir libertina*, *Viviparus japonicus*, *V. longispira*.

MIKI (1948): plants: *Pteridium aquilinum*, *Cephalotaxus obovata*, *Abies firma*, *Tsuga oblonga*, *Cryptomeria*, *Fagus hayatae*, *Zelkova ungeri*, *Berberis longispinus*, *Parabenzoin praecox*, *Neolitsea aciculata*, *Hamamelis parrotioides*, *Rosa akashiensis*, *Gleditschia japonica*, *Berchemia racemosa*, *Paliurus nipponicns*, *Camellia japonica*, *Elaeagnus akashiensis*, *Trapa macropoda*.

In addition, *Stegodon orientalis* was found at the horizon just above the *Sakura* volcanic ash layer, and *Elephas shigensis* was discovered at the horizon near the *Pink* volcanic ash layer.

b. Ryuge sand and gravel

This is the top gravels of the Kobiwako group. It is well exposed at the south of the Ryuge, and consists of cobble-pebble gravel beds and coarse-grained sand beds.

3. Regional stratigraphy of the Tokai group in northern part of Mie Prefecture (Fig. 6 and Table 8)

The Age subgroup of the Tokai group of this region is divided into six formations as shown in Table 8.

1) Biroku formation. (80m)

This is a gravel facies deposited at the mouth of an ancient river streamed down from the Yôrô Mountain Range made of the upper Paleozoic strata. Therefore, the facies rapidly varies laterally. It pinches out and is replaced by the marginal clay facies with gravel and lignite of the lower part of the Kono formation.

2) Kono formation (20-130m)

This formation is composed of massive, bluish green clays with several seams of lignite. Although it attains a thickness up to 130m in the east part of the surveyed area, near Kono it is decreasing westward measuring 20m at Kawahara.

MATSUI (1942) and KATO (1957) obtained plant-fossils from the bottom of a river near Kono, namely *Glyptostrobus pensilis*, *Metasequoia disticha*, *Juglans cinerea*, *Styrax* sp..

A very characteristic volcanic ash bed is intercalated in the middle horizon of this formation. This is a dacitic volcanic ash layer corresponding to the *Masugi* volcanic ash layer of the Kobiwako group on various criteria. This is called the *Dacite* volcanic ash layer by ISHIDA and YOKOYAMA (1969) and ISHIDA *et al.* (1969). NRM of this volcanic layer, sampled at Kawahara, has a reversed polarity, which is correlated with the Mammoth event in Gauss Normal Epoch (ISHIDA *et al.*, 1969).

3) Ichinohara formation (200m+)

This formation is chiefly consisting of alternations of massive clay and rounded gravels of pebble size. It is 100m in thickness near Ichinohara. The equivalent formation is represented by thick sand layers (280m) containing cobble and pebble gravels near Kuwana City (KATO, 1957).

MIKI (1941) obtained fossil plants *Metasequoia*, *Juglans cinerea* and others at Tado, and *Glyptostrobus pensilis*, *Picea koribai*, *Sequoia sempervires* at Shimofukaya. MATSUI (1942) reported *Acer pictum*, *Alnus tinctoria*, *Quercus serrata*, *Q. criopula* from Chikarao.

4) Kuragari formation

This gravel formation measuring a little over 100m in thickness at the north of Kuragari, diminishes westwards and replaced by the lower part of Oizumi formation in northeast area of Ageki. Rounded cobbles and pebbles of paleozoic rocks, mostly cherts, are rich in this formation.

5) Oizumi formation (400-200m)

This is composed mainly of alternations of sand and clay with gravel lenses and volcanic ash layers. The *Pumice* volcanic ash layer, one of the good key beds in the Plio-Pleistocene series of Kinki and Tôkai area is inserted in the

my.	stage	TAKEHARA (1961)	KATO and KUWABARA (1967) Seto sub group	Writer (1969)		
				Age sub-group volcanic ash layer	formation	whole area
	Middle Gravel stage	Komeno Bed (180m)	Karayama Bed (10m+)		Komeno formation	Komeno gravel formation (200m+)
2.0 2.5	Gamo stage	Oizumi Bed (350m) Kuragari Bed (150m)	Idaka facies	*Sakuradani* (Ho) *Pumice* (T8)	Oizumi formation Kuragari formation	Oizumi formation (400m)
3.0	Sayama stage	Kameyama Bed (350m) Kusuhara lignite bearing Bed (400m)	Owari coal-bearing facies	*Kaigake* (T5) *Masugi* (*Dacite*; T2) *Yubune* (*Nuka*; T1)	Ichinohara formation Biroku f.	Kameyama formation
	Iga-Aburahi stage	Koyama gravel Bed (250m)	Mizuno sand and gravel facies	*Tsu* (T1)		Kusuhara formation Koyama formation
4.5	Seto stage		Seto ceramic clay Bed			Seto ceramic clays

Table 8. Stratigraphy of the Tokai group.

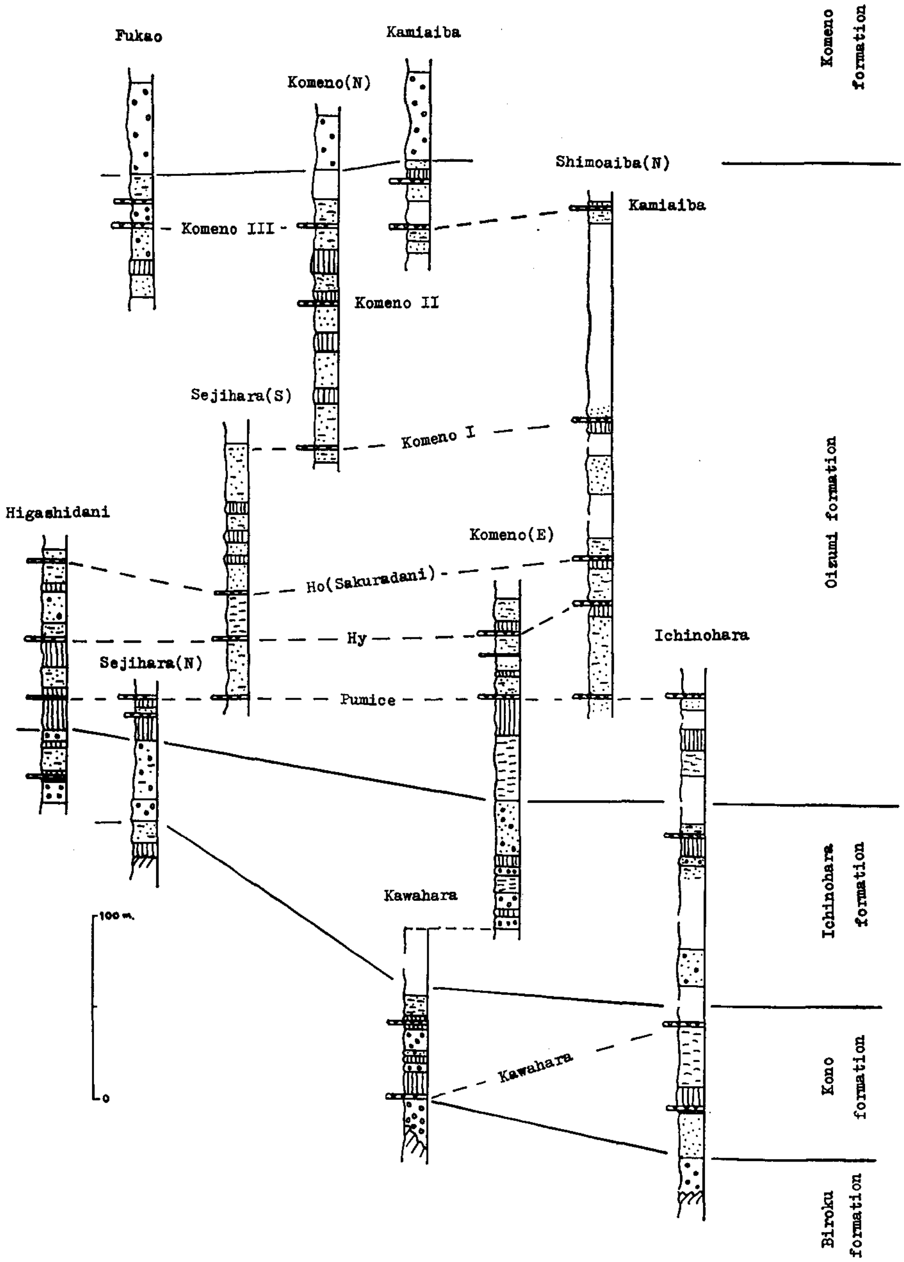


Fig. 6. Columns of the Age sub-group in Inabe-Kuwana region. (The marks are same in Fig. 5.)

lower part.

Stegodon akashiensis occured in the upper and middle parts of this formation. *Metasequoia disticha*, *Juglans cinerea*, *Picea koribai*, etc. are also known.

6) Komeno formation (200m+)

This is the top gravels of the Tokai group. Subround paleozoic sandstone gravels of boulder and cobble size are dominant.

PART II PALEOGEOGRAPHY OF THE EASTERN SETOUCHI GEOLOGIC PROVINCE, WITH SPECIAL REFERENCE TO PALEOCURRENT AND MIGRATION OF BASINS.

1. Paleocurrent directions deduced from the cross beddings.

The cross beds which are inclined to the principal surface of accumlation, are frequently observed in the sandy facies of the Plio-Pleistocene in Kinki and Tokai districts. Tabular and trough types are dominant and others are absent.

It has been shown that the directions of maximum dip are well concentrated in the Plio-Pleistocene sediments of lake origin (YOKOYAMA, 1968). The paleocurrent directions are thought to be parallel with the mean directions of maximum dip of cross beddings in the Plio-Pleistocene of Kinki and Tokai areas as discussed in many other reports (see. POTTER and PETTIJOHN, 1963).

Angles of inclinations and azimuths or directions of maximum dips of cross beddings are measured in some areas. The method of measurement has been reported by YOKOYAMA (1968).

1) Eastern half of the Osaka group

a. Takatsuki area

The directions of cross beddings and inclinations of gravels were measured by the writer, S. HASHIMOTO and Nishiyama Research Group. The horizons are mostly between Ma 1 and Ma 2. The results are shown in Fig. 7 and Table 9.

Roughly speaking, the directions of maximum dips are divided into two groups: from northeast to southwest and from southeast to northwest. The former, which is mainly observed in the northeastern part of the Takatsuki area (a in Fig. 7), is mostly seen in medium to coarse sand beds or gravel beds, and the latter, which is found in the western area (c in Fig. 7), is seen in coarse sands. In the middle part of the Takatsuki area, both directions are observed, and especially at Hattori and Ankoji (B 13, H 33 and B 11), the two directions are found at the same cliff. The former is formed by the ancient river Akuta and the latter is the product of the ancient river Yodo. The change of lithofacies between Ma 1 and Ma 2 accords with the paleocurrent directions, namely, cobble-pebble gravels are dominant in the northwestern part, while medium to coarse sand layers are rich in the southwestern part of this area.

horizon	site-number	locality	direction of vector means	consistency ratio	type	measured number	number of set	thickness of set	average dip angle
under Ma1	T2a	Kaminokuchi	275	98.3	trough	10	1	0-50	18.6
	T2b		280	98.0	imbri.	20	-	—	18.8
	B1-1		251	85.8	〃	11	-	—	24.9
	B1-3		254	73.5	〃	10	-	—	29.0
	B1-19		267	87.3	〃	9	-	—	24.6
	T2c		266	91.2	〃	5	-	—	26.8
	H-104	Tojo	253	90.7	tabular	13	1	0-30	18.0
	H-105		173	99.2	〃	5	1	0-18	36.6
			205	80.9	imbri.	6	-	—	23.5
	H-110	North Park	225	99.2	tabular	4	1	20-40	13.0
			272	94.5	imbri.	11	-	—	38.3
	H-111	Central Park	204	98.3	tabular	8	1	15	23.6
	H-112	Nariai	306	96.6	〃	5	1	0-15	26.2
	H-113		262	96.3	imbri.	11	-	—	11.8
	H-114		294	94.6	〃	13	-	—	21.2
	H-115		326		〃	8	-	—	30.5
	H-44		121	97.8	tabular	5	1	100	14.8
	C9-A		145	90.0	〃	15			25.2
just under Ma 1	H-100	Kaminokuchi	204	97.5	tabular	8	1	0-30	25.6
	H-102	Tojo	239	97.3	〃	7	1		17.3
Ma 1	H-42	Iwate School	247	98.4	〃	5	1		30.4
Ma 1 / Ma 2	T5	Tsukahara	223	92.6	imbri.	12	-	—	16.8
	T1	Nasahara	231	94.3	tabular	17	4	10-15	25.0
	B2-A	Kaminokuchi	270	97.3	〃	3	1		16.7
	B10-1	Matsugaoka	266	51.1	imbri.	15	-	—	27.9
	B10-3		241	61.1	〃	17	-	—	34.7
	B11-2	Ankoji	219	79.8	imbri.	16	-	—	27.9
	B11-3		231	86.3	tabular	15	1	40	17.6
	B11-6		164	64.4	〃	15	1		14.9
	B13-7	Hattori	271	89.5	〃	20	4	10-20	18.3
	B13-29		155	90.6	〃	16			17.5
	C5-15	Hiyoshidanchi	265	92.9	〃	9	1	10-70	18.9
	H-6	Nasahara	193	94.3	〃	8	1		18.3
	H-8	Hiyoshidai	164	98.4	〃	5	1		17.0
	H-10b		259	90.1	〃	6	1		28.0
	H-33a		156	99.2	〃	5	1		19.0
	H-33b		280	94.4	〃	10	1		27.5

horizon	site-number	locality	direction of vector means	cosistency ratio	type	measured number	number of set	thickness of set	average dip angle
	H-36b		266	96.2	〃	5	1		25.2
	H-43	Bessho	146	98.8	〃	5	1		22.8
	H-55	Hattori	194	99.4	〃	5	1		25.0
	H-70	Nisseki	311	99.2	〃	5	1		28.8
	H-101	Kaminokuchi	244	69.4	imbri.	17	-	—	27.6
	H-108	North Park	250	90.5	tabular	8	1		17.5
	H-117		311	99.4	imbri.	19	-	—	36.2
	H-118		310	95.7	tabular	3	1		27.3
Ma 2 / Ma 3	H-10a	Nasahara	183	99.6	〃	5	1		15.6
	H-11a	Ozôji	147	96.5	〃	4	1		12.3
	H-12a	Nasahara	177	87.1	〃	6	1		10.0
	H-36a	Hiyoshidai	159	97.8	〃	8	1		25.8
Ma 3 / Ma 4	H-11b	Ozôji	228	96.1	〃	10	1		19.8
	H-12b	Nasahara	201	92.8	〃	6	1		22.3
	H-37a	Hiyoshidai	203	96.8	〃	5	1		19.8
	H-37b		200	95.4	〃	15	2		20.6
Ma 4 / Ma 5	H-12c	Nasahara	201	97.3	〃	3	1		20.7
	H-39	Anshoji	97	97.8	〃	5	1		18.4
	H-71	Nisseki	181	96.8	〃	5	1		21.6
Ma 5 / Ma 6	H-12d	Nasahara	296	99.0	〃	4	1		20.0
	H-40	Anshoji	218	91.6	〃	6	1		19.2
	H-80	Okamoto	200	99.0	〃	5	1		14.8

Table 9. Paleocurrent directions from the measurement of cross bedding in Takatsuki region. Paleocurrent direction, that is, vector means are represented by anticlockwise angle from east direction. (partly by Nishiyama Research Group, 1969)

b. Nishiyama area

The horizons in which the directions of cross beddings are measured are Ma 3 and up to Ma 6. As in the case of the Takatsuki area, two directions are recognized; northeast to southwest and northwest to southeast. The former is formed by the current of the ancient river Katsura and the other is made by the ancient river Obata. The coarser sediments are rather rich in the eastern half of this area, as seen in E-W section along the national road, Route 9, where the clay beds decrease in thickness eastward and the mean direction of the paleocurrents is almost southwest. The results are summarized in Fig. 8 and Table 10.

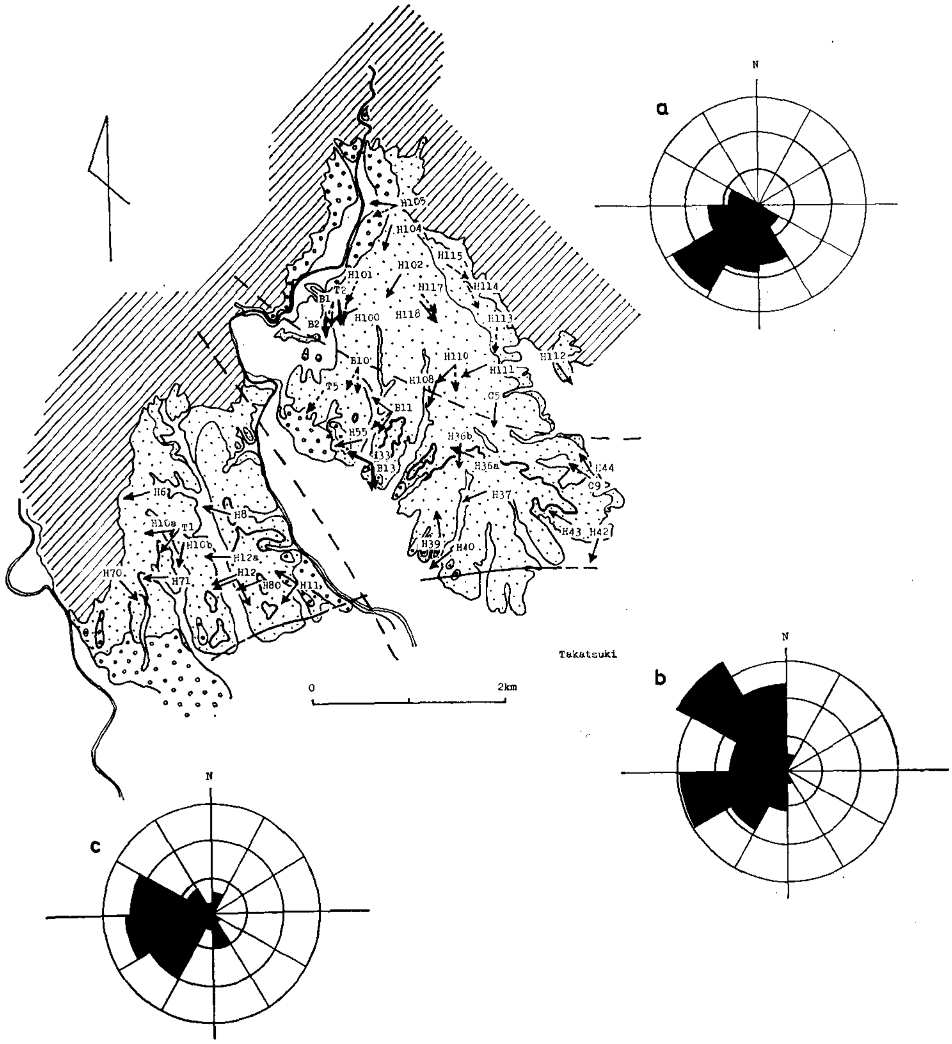


Fig. 7. The directions of cross beddings and inclination of gravels in Takatsuki Area. a: northeastern part, b: middle part, c: western part.
←—: average directions of cross beddings
←···: average directions of inclination of gravels

c. Uji area

The data were collected mainly by S. HASHIMOTO and S. MORIGUCHI, and were summarized by the writer.

Generally speaking, the paleocurrent directions to west or northwest are prevailing. But the directions from southwest to northeast are also recognized

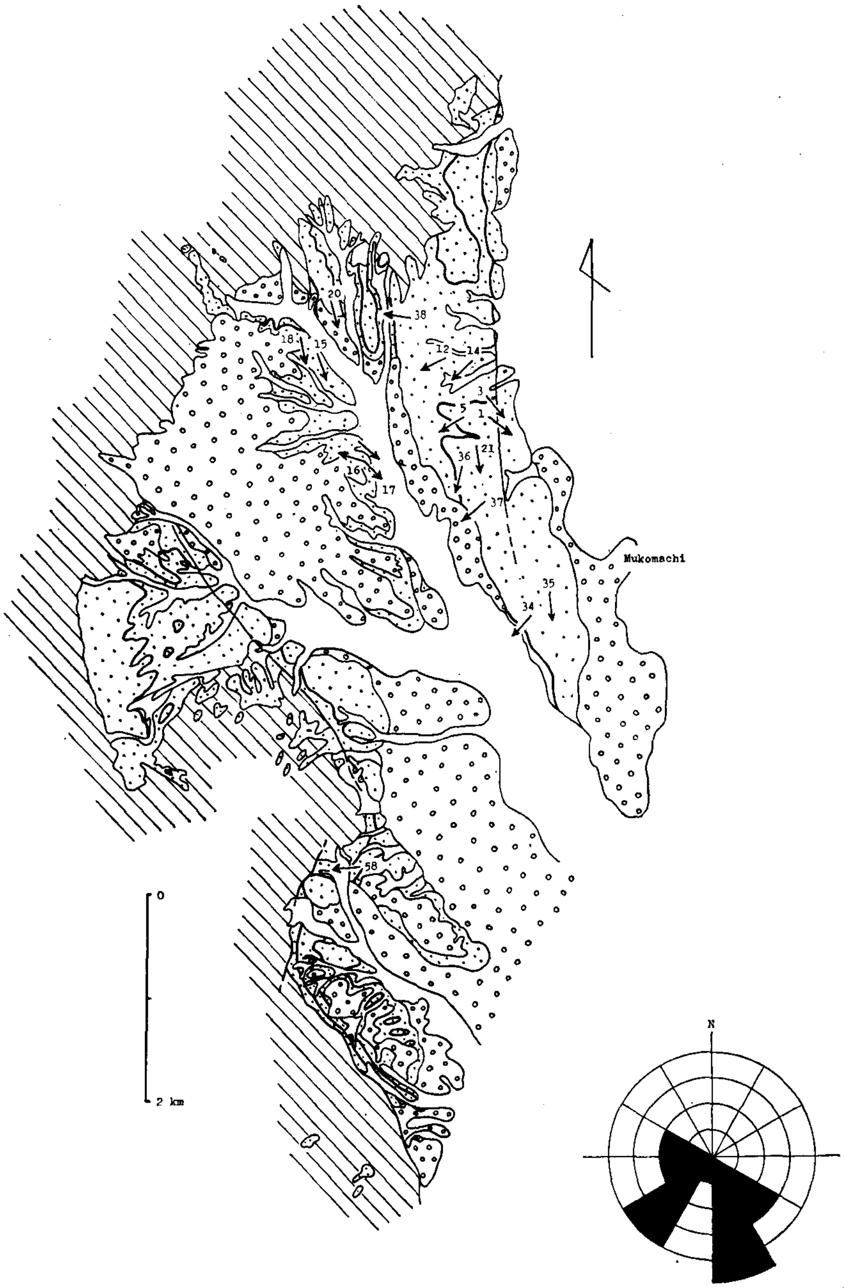


Fig. 8. The directions of paleocurrent deduced from cross beddings in Nishiyama Area.
←—: average directions of paleocurrents

horizon	locality number	locality	direction of vector means	consistency ratio	type	measured number	number of set	thickness of set	average dip angle
above Ma 6	M-34	Higashiyama	228	97.3	tabular	15	1	50	31.7
	M-35	Higashiyama	277	92.9	〃	15	1	50+	30.3
	M-36	Mozume	256	95.3	〃	15	1	15	25.6
	M-37	Higashiyama	221	96.0	〃	5	1		23.0
	M-1	Mozume	325	99.0	〃	15	1	150	44.9
	M-5	Mozume	210	98.5	〃	10	1	30	24.4
	M-21	Mozume	281	94.6	〃	15	1		18.1
between Ma 6 and Ma 4	M-3	Mozume	310	99.3	〃	15	1	20	18.2
	M-17		324	95.9	〃	11	1		12.2
	M-16		164	98.9	〃	16	1		25.5
	M-58	Hashirida	185	87.6	〃	10	1		27.8
	M-15	Kutsukake	291	89.0	〃	15	1	50	22.8
	M-20	Tsukahara	286	88.7	〃	10	1	50	31.9
between Ma 4 and Ma 3	M-12	Nakayama	206	99.8	〃	15	2		28.5
	M-14	Katagihara	225	98.1	〃	11	2		18.5
between Ma 3 and Ma 2	M-38	Nakayama	171	85.1	〃	10	2	20	24.5
	M-18	Kutsukake	282	78.8	〃	7	1		13.8

Table 10. Results of measurement of cross beddings in the Nishiyama area. Paleocurrent directions, that is, vector means are represented by anticlockwise angle from east direction.

in this area, for example, at locality, A 1, D 12, D 9, H 4, E 11 and G 4 in Fig. 9. Both of these are found together at the one and same cliff, where the former formed by the ancient river Uji are found in coarse sand or medium sand facies and the latter formed by the ancient river Kizu are found in the coarse or granule facies. The results are shown in Fig. 9 and Table 11.

d. The other area of the Osaka group

The mean directions are shown in Fig. 10. The data of Nara, Tanabe and Hirakata were collected by Y. NAKAGAWA and those of the other areas were collected by the writer.

In the western part of Nara City, two directions are recognized, from north to south and from south to north. Generally speaking, the paleocurrents have southward directions in the lower horizon, while they turn northward in the upper horizons.

In Yawata-cho, the mean directions of paleocurrents are from northeast to

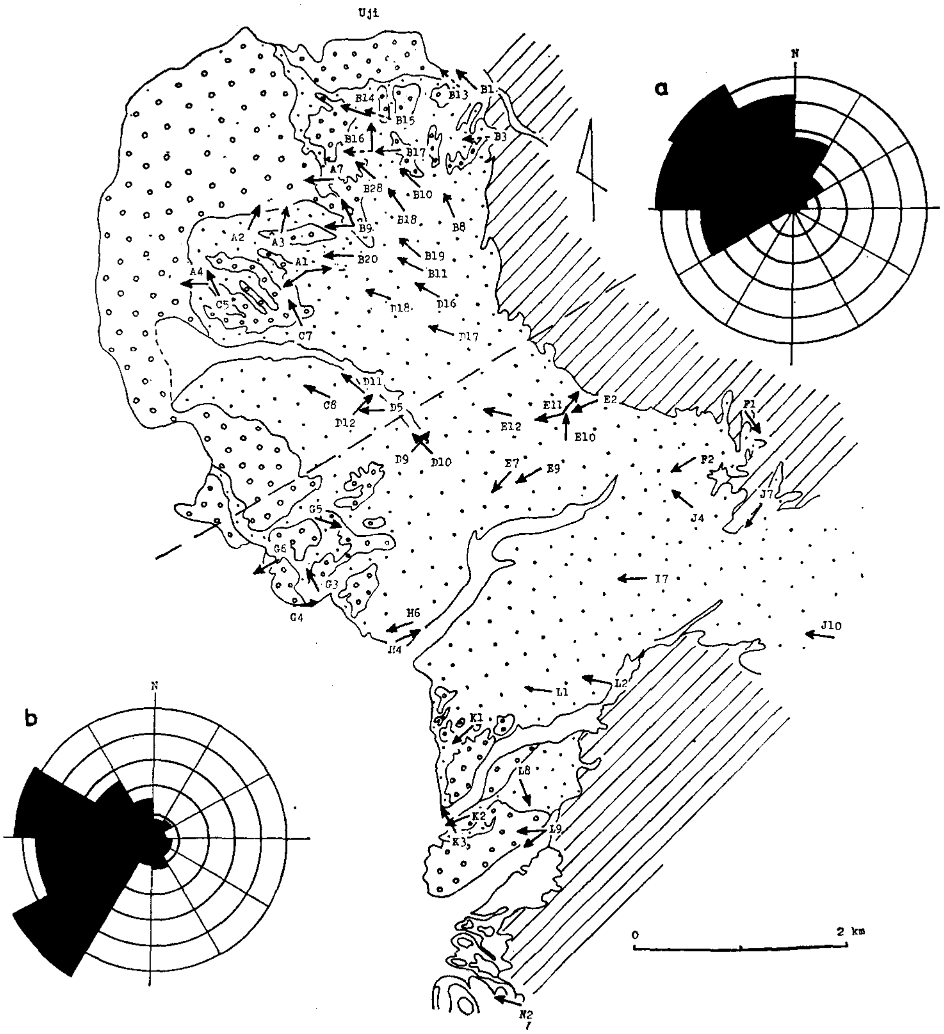


Fig. 9. The directions of cross beddings and inclination of gravels in Uji Area.
a: northern part, b: southern part.
←—: average directions of cross beddings
←---: average directions of inclination of gravels.

southwest as usual (NAKAGAWA, 1969).

In Senpoku and Sennan areas, all directions of cross beddings are from east to west.

2) Kobiwako group.

The summarized directions of cross beddings are shown in Fig. 11.

site-number	direction of vector means	consistency Ratio	type	measured number	thickness of set	average dip angle
A-1	6	96.4	tabular	10	10-15	22.0
A-1	214	95.0		4		19.5
A-2	65	97.5		16	15-20	27.6
A-3	77	98.5		10	50	25.6
A-4	178	97.5		8		23.5
A-7	180	96.5		10		24.4
B-1	240	93.7		8		16.5
B-3	186	93.0	imbri.	7		32.1
B-8	115	96.0	tabular	10		30.5
B-9a	182	96.2		11		21.4
B-9b	116	97.7		9		13.2
B-10	139	96.6		14		27.9
B-11	153	97.8		12		24.3
B-13	138	93.6	imbri.	9		30.0
B-14	160	98.5	tabular	10	50	23.4
B-15	160	98.3	imbri.	3		34.3
B-16	179	92.7		8		28.8
B-16	92	97.5	tabular	12		25.8
B-17	182	93.5		8		20.0
B-18	123	96.0		5		15.6
B-19	137	96.0		5		26.8
B-20	180	93.3		3		14.0
B-28	139	97.1		10		25.7
C-5	114	95.0		10		18.0
C-7	115	80.1		6		17.5
C-8	154	96.4		8		9.5
D-5	180	96.7		15	30	22.3
D-9	48	91.1		4		13.0
D-10	134	87.6		9		17.3
D-11	139	82.1		4		6.5
D-12	46	100.0		2		12.5
D-16	149	98.5		7		24.8
D-17	160	96.0		5		21.2
D-18	160	96.6		3		22.0
E-2	208	86.7		3		20.0
E-7	226	99.6		10		25.5
E-9	210	96.4		8		27.5
E-10	88	95.0		7		21.4
E-11a	53	98.0		7		26.9
E-11b	192	89.1		5		22.0
E-12	166	97.2		11		12.7

site-number	direction of vector means	consistency ratio	type	measured number	thickness of set	average dip angle
F-1	305	97.4		10		50.0
F-2	210	93.3		12		15.0
G-3	116	81.2		10		13.0
G-4	8	87.9		10		15.3
G-5	341	95.4		5	40	16.2
G-6	208	72.7		10		14.6
H-4	25	77.9		10		15.6
H-6	201	98.5		12		27.1
I-7	179	98.1		10		14.5
J-4	139	99.3		6		34.2
J-7	235	98.1		10		17.8
J-10	171	98.8		10		18.7
K-1	219	93.5	tabular	13		25.0
K-2	203	87.1		7		20.0
K-3	119	94.7		7		21.6
L-1	172	97.0		10		9.2
L-2	168	97.5		12		16.6
L-8	292	96.9		10		22.5
L-9a	216	97.9		10		21.0
L-9b(SU-21)	182	94.4		10		18.2
N-2	163	94.9		10		13.2

Table 11. Results of measurement of cross beddings in Uji-area. Paleocurrent directions, mean of vectors, are represented dy angle from east anti-clockwise.

a. Kosei area.

Although the measurements are very few in number, all of them have the directions which are roughly north to south. Their horizons are under the *Azuki* and near the *Sakura* volcanic ash layers. The results are presented in Fig. 11 and Table 13.

b. Konan area

At five sites, the mean directions are southward. The horizon is near the *Mushono* (*Pumice*) volcanic ash layers. The results are shown in Fig. 11 and Table 14.

c. Kotô area.

The paleocurrent directions were measured in the Kazuraki and Sunazaka sand member, the middle part of the Sayama formation. The results have been reported by the writer (1968). The paleocurrent directions are shown in Figs. 11 and 12, and Table 15. They have the azimuth as the mean value of vectors from north to south in the Kazuraki member, while the directions turn to north

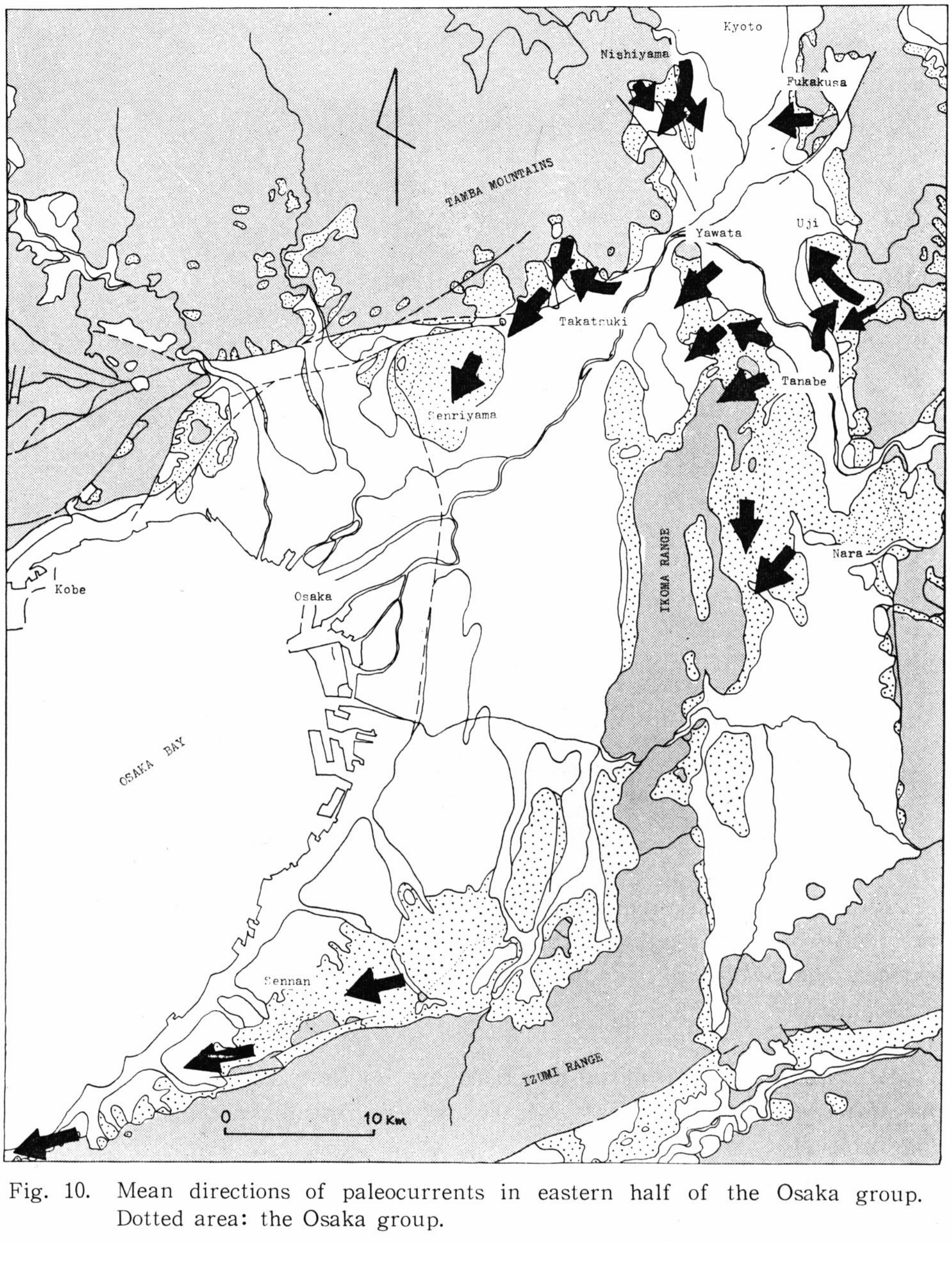


Fig. 10. Mean directions of paleocurrents in eastern half of the Osaka group. Dotted area: the Osaka group.

site-number	horizon	locality	direction of vector means	consistency ratio	type	measured number	number of set	thickness of set	average dip angle	district
F-001	Ma 4/Ma 3	Fukakusa	147	97.9	tabular	15	2	17	22.3	Kyoto
F-003	under Ma3	Fukakusa	188	98.2	〃	20	1	20	24.8	
F-004	under Ma5	Fukakusa	151	97.7	〃	10	1	40	28.0	
N-14	under Ma2	Nara	114	98.5	trough	20	2	15	25.2	Nara
Se-73	under Ma1	Kumatori	208	99.4	〃	10	3	30	27.1	Sennan
Se-82	under Ma3	Takano	139	94.3	tabular	14	2	20	22.7	
Se-93		Misaki	194	93.4	〃	15	2	40	13.2	

Table 12. Results of measurements of the cross beddings in Osaka group except Table 9, 10 and 11. Paleocurrent directions, namely means of vector are represented by anticlockwise angle from east direction.

in the Sunazaka member.

The thickness and maximum grain-size in the Kazuraki Sand are shown in Figs. 13, 14. Variation in maximum grain sizes parallel with the paleocurrent are shown in Fig. 15. The Kazuraki Sand increases in thickness and decreases in its maximum grain size downstream as shown by the cross beddings. The paleocurrent directions accord with other sedimentological criteria in general.

3) Tokai group

a. Northern part of the Age subgroup (Inabe-gun, Mie Prefecture)

The Plio-Pleistocene series in this area corresponds to the Sayama, Gamo and Yôkaichi formations of the Kobiwako group. The paleocurrents have a general direction from north to south in the central part of the basin. This direction is subparallel to the longitudinal axis of the depositional area, *i. e.* the Makita Graben. But the paleocurrent directions are almost at right angles to the axis of the basin near the basement mountains, the Yoro Range.

The mean vectors of cross beddings are toward the south in the lower and middle parts, respectively given the names, Ichinohara and Ooizumi formations, whereas they turn north in the upper part, the Komeno gravel formation.

The results are summarized in Figs. 11, 16 and Table 16.

4) Significance of vertical changes of paleocurrent directions in several areas

It was recognized in Age, Kotô and Nara regions that the paleocurrent changes from the southerly direction in the lower horizon to the northerly direction in the upper horizon. This fact suggests that the southern zone of the Setouchi Province began to upheave in the period of the turn toward the opposite direction, and that the northern zone, containing Lake Biwa and Osaka Bay, began to subside rapidly.

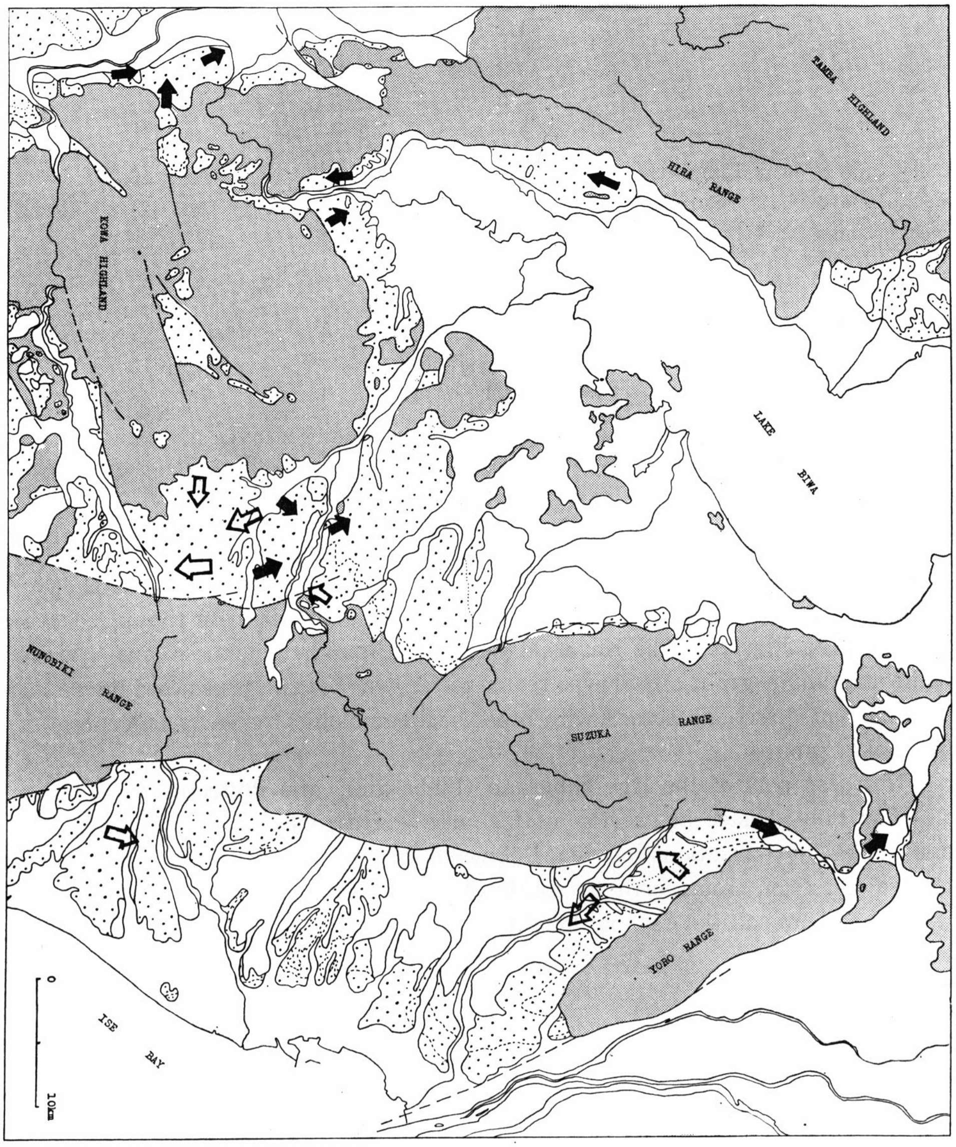


Fig. 11. Mean directions of paleocurrents in Kobiwako and Tokai groups. Dotted area: Kobiwako and Tokai group. (⇦; lower horizon, ⬅; upper horizon)

2. Migration of sedimentary basins and geotectonic development of the Setouchi Geologic Province of Central Japan in Plio-Pleistocene age

1) Migration of the sedimentary basins.

It has been noticed by many investigators that the horizons of the southern

horizon	site-number	locality	direction of vector means	consistency ratio	type	measured number	number of set	thickness of set	average dip angle
Mina-misho clay	BW-7a	Kurihara	273	99.5	tabular	10	1		29.7
	BW-7b	Kurihara	267	99.8	〃	6	1		33.8
Wani sand	BW-2	Kurihara	345	95.3	〃	6	1	120	25.0
	BW-5	Wani	205	94.5	trough	15	3	45	31.0

Table 13. Results of measurements of the cross beddings in Kosei region. Paleocurrent directions, that is, vector means are represented by anticlockwise angle from east direction.

zone are generally lower than those of the northern zone in the Setouchi Province. Namely, the sedimentary basins are considered to have migrated from south to north. The writer (1968) mentioned that the mountain ranges having the meridional trend, for example, the Suzuka Ranges, began to upheave before the sedimentation of the Plio-Pleistocene series. So that, the fundamental form of the present topography of the Kinki area was originated before the sedimentation of the Kobiwako and Osaka groups, and the present geomorphological features are not essentially different from those of the early Kobiwako age. The migration of the sedimentary basins where the Plio-Pleistocene series deposited, is considered to be as shown in Figs. 17-21. These paleogeographical maps are based on the lithofacies and the changes of the paleocurrent directions in the same horizon which is determined from many tephras.

2) Division of the Plio-Pleistocene Age in the Setouchi Province

a. Pre-Second Setouchi stage.

No sedimentation took place through out the 4-5 million years before the Plio-Pleistocene series began to deposit about 4.5 million years ago. Though the

horizon	site-number	locality	direction of vector means	consistency ratio	type	measured number	number of set	thickness of set	average dip angle
Zinryo Sand	Su-28	Ishiyama	280	95.5	tabular	20	2	20	14.3
	Su-27	〃	267	95.3	〃	15	2	10	15.9
	Su-26	〃	261	97.3	〃	15	2	40	15.0
Seta Gravel II	Su-25	Shiga Univ.	230	95.9	〃	15	2	10	11.6
	Su-24	〃	215	99.4	〃	5	2	10	15.2

Table 14. Results of measurements of the cross beddings in Konan region. Paleocurrent directions are represented by anticlockwise angle from east direction.

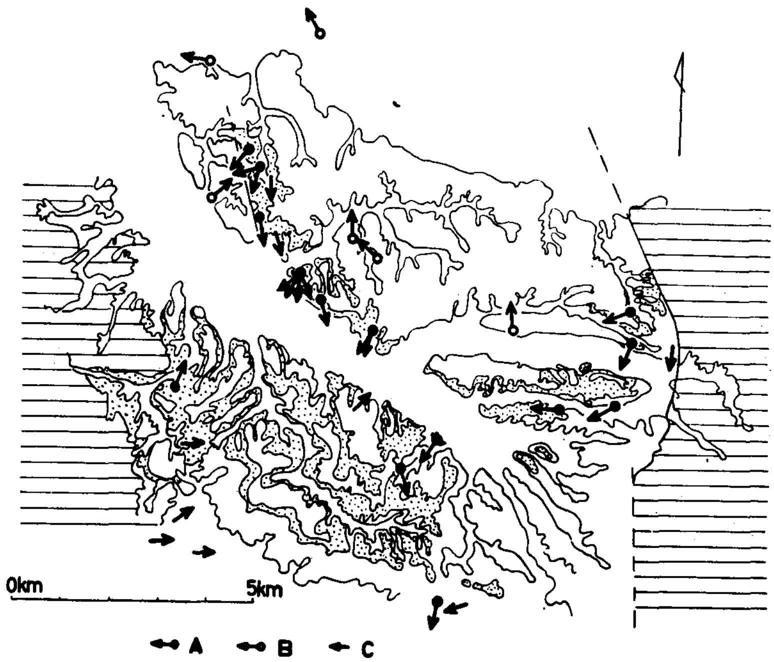


Fig. 12. Paleocurrent directions, means of vector, in Kazuraki and Sunazaka members of the Sayama formation.
A: mean directions in the Kazuraki member.
B: mean directions in the Sunazaka member.
C: generarized directions of cross beddings.

topography in this stage cannot be clarified in detail because there is no sediment, it is considered that the topographical features were slightly undulating form like the peneplain throughout this stage.

b. Seto stage

This stage is characterized by the ceramic clays which deposited in the small low grounds at Seto and Iga regions. The basement of these low grounds was composed mainly of granitic rocks. The diameter of these depressions ranges from a few hundred meters to a few kilometers, scattered in the wide and evenly undulated plain.

c. Iga-Aburahi stage

This stage is represented by the basal gravels of the Plio-Pleistocene series in Kinki and Tokai districts. The Koyama gravels, Mizuno gravels and Iga-Aburahi formation were deposited in this stage. Coarse sediments such as cobble or pebble gravels and very coarse sands are dominant. This fact indicates the beginning not only of the subsidence of the southern zone, namely,

horizon		site-number	locality	direction of vector means	consistency ratio	type	measured number	number of set	average dip angle
Gamo formation		195	Minakuchibashi	165	99.2	tabular	13	1	16.9
		11	Shinjio	152	95.2	〃	10	1	14.5
Sayama formation	Sunazaka sand member	7	Oki	92	98.0	trough	20	4	27.1
		13	Uchikoshi	133	97.7	tabular	15	2	24.8
		37	Fukawa	48	98.0	〃	10	1	18.2
		53	Oharaueda	92	95.3	〃	15	1	13.2
	Kazuraki sand member	28	Mobira	280	96.7	〃	7	1	26.4
		16	〃	233	94.6	〃	15	1	17.2
		46A	Takano	242	98.3	〃	12	1	24.8
		46B	〃	246	99.7	〃	10	1	26.6
		57	Kami	245	98.5	〃	8	1	9.5
		165	Dodoike	55	97.7	〃	13	1	15.2
		185	Iwamuro	205	98.7	〃	8	1	18.0
		211	Terasho	290	96.6	〃	12	2	20.2
		3A	Momoyama	227	96.7	〃	11	1	24.3
		3B	〃	248	96.9	〃	13	1	22.9
		3C	〃	260	90.0	〃	15	3	21.6
		3D	〃	205	99.5	〃	20	2	29.2
		210	Kazuraki	282	91.3	〃	15	1	20.2
		33A	Omitobashi	202	96.0	trough	15	1	22.7
		33B	〃	190	99.5	tabular	10	1	18.5
		175	Mushono	236	98.0	〃	20	3	22.7
Aburahi formation		204	Higashide	260	98.4	tabular	10	2	20.0
		155	Ichiuno	167	96.7	〃	9	1	11.6
		59	Shimoda	210	98.0	〃	15	1	12.7

Table 15. Paleocurrent directions deduced from cross beddings in Koto region. Paleocurrent direction, that is, vector means are represented by anticlockwise angle from east direction.

the southern part of the ancient lake Tokai, the Iga Basin and the ancient lake Shobudani, but also of the upheaval of the southern mountainlands. This crustal movement is here called "Mizuno phase in the Rokko crustal movement". In the latest period of this stage, a few small ancient-lakes appeared in the Tsu and Aburahi regions.

Nyssa and *Carya* existed during this stage.

d. Sayama stage

The chain-like lakes lay along the line of E-W trend. The submerged area

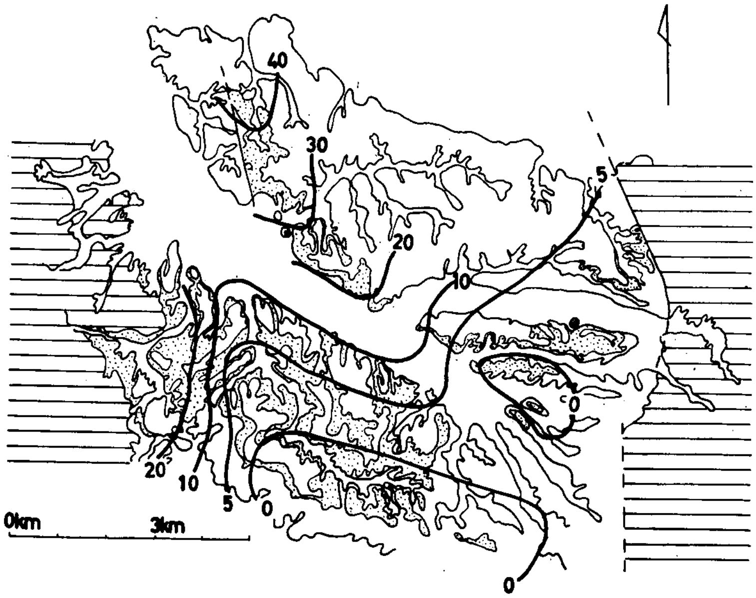


Fig. 13. The isopach map of the Kazuraki Sands, Sayama formation. 40: 40m in thickness.

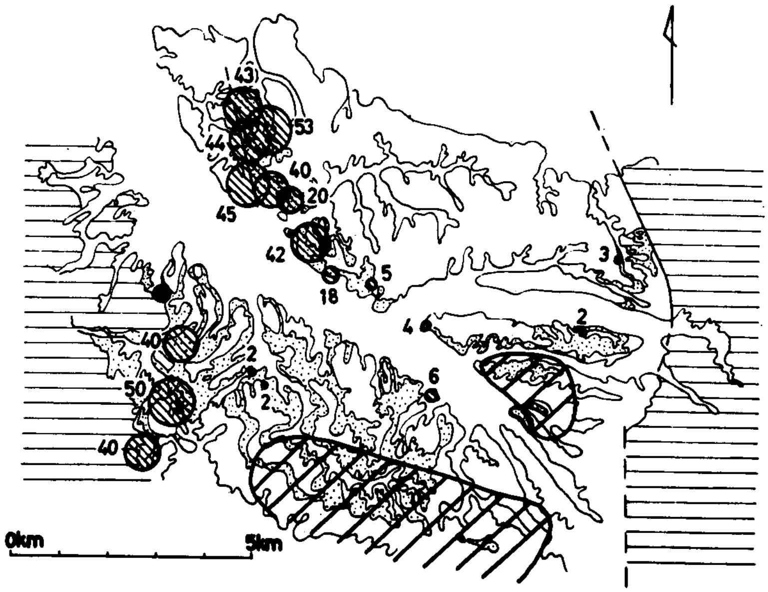


Fig. 14. Maximum grain size of the Kazuraki member, Sayama formation. The area of inclined line: only clay beds in the horizon of the Kazuraki Sand member.
40: 40cm in diameter of the maximum grain.
●: 200cm in diameter of the maximum grain.

extended over the entire area of the Tokai group and a wide lacustrine environment appeared in the Nobi Plain. Moreover, an ancient lake was formed in Sayama region. Fine-grained materials such as clay and fine or medium sand of the Sayama formation were deposited in this ancient-lake. At the same time, the thick clay beds containing the *Shobudani* volcanic ash layer and some vivianites, were deposited in the ancient lake Shobudani. Thus, this stage is characterized by the predominance of lacustrine clays.

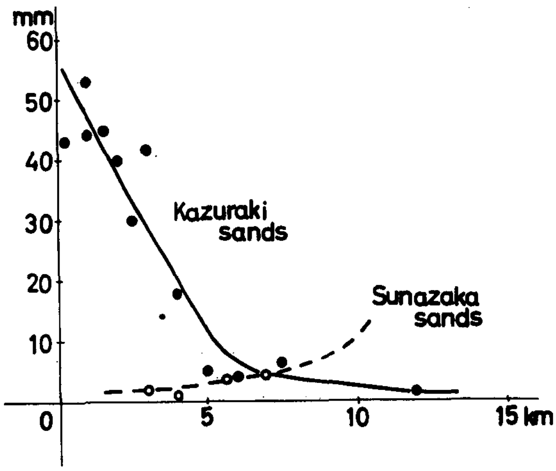


Fig. 15. Change of the maximum grain size along the direction parallel to the paleocurrent.

The subsidence of the southern zone ended in the middle period of this stage. Then the northern zone, which is here called "the Biwako-Osaka Subsidence Zone", *i. e.* the boundary regions of the Ryoke and Tamba Terrain, began to subside continuously, as deduced from the 180° turn of the paleocurrent directions.

Probably *Carya* was extinct already, but *Nyssa* and *Stegodon elephantoides* existed in this stage.

e. Gamo stage

The subsiding centers of basins had been migrating to the north since the late Sayama stage. They reached the boundary region of the Ryoke and Tamba Terrains: Inabe-Kuwana region in the ancient lake Tokai, Hino in the ancient lake Biwa. Also in Nara and Osaka regions, some lakes appeared, while the Shobudani lake disappeared in this stage or in the next. The *Pumice* volcanic ash layer is widely deposited in all the lakes. This stage is characterized by alternations of sand and clay with some marginal gravels.

f. Middle gravel stage

In this stage, coarser sediments such as cobble or pebble gravels became very dominant in the Plio-Pleistocene series, for example, the Komeno formation, Karayama formation, Yokaichi gravel formation, Uji-Tanabe gravels and Kawachinagano gravels. These coarse materials were transported from the southern mountainland and the meridional mountain ranges that are separating the basins. It may be certain not only that these mountainlands rapidly upheaved in this stage but also that the northern zone (the Biwako-Osaka Subsidence Zone) began to subside successively. This tectonic movement is here named the "Suzuka phase in the Rokko crustal movement",

Metasequoia disticha was prosperous throughout this stage and the next, while the *Metasequoia* flora was extinct.

Stegodon akashiensis existed during this stage.

g. Nara stage (from the *Yellow* volcanic ash layer to Ma 2 in horizon)

The shallow marine or lagoonal environment extend over Nara, Kyoto, Osaka and Harima regions.

In the western part of the Nara Basin, some marine clay beds, Ma 0, Ma 1 and Ma 2 were discovered by NAKAGAWA (1967). On the other hand the horizons of Ma 0 and Ma 1 are of lacustrine facies in Fukakusa and Nishiyama regions in the Kyoto Basin, though a marine clay bed of Ma 2 horizon is found in the same areas. These three marine clay beds are also seen in the Osaka and Harima regions.

NAKANISHI *et al.* (1969, MS) obtained the following diatoms from the horizon near the *Yellow* volcanic ash layer at some places of the Osaka Plain: *Coscinodiscus lacustris*, *Cos. rothii* var. *normanii*, *Cos.* cf. *commutatus*, *Cyclotella striata*, *Cyc. stylorum*.

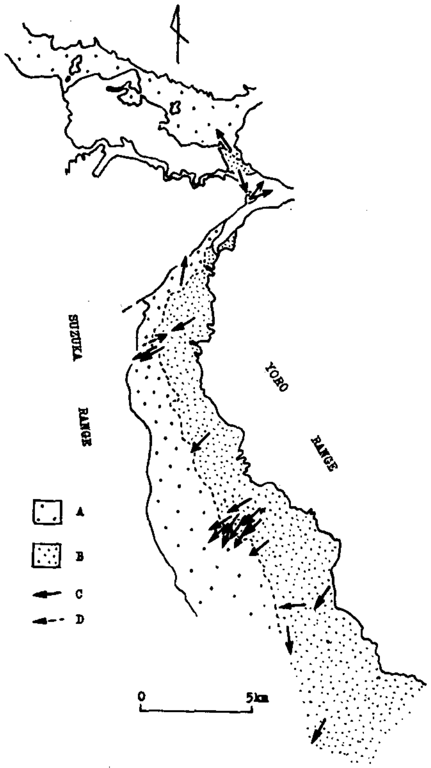


Fig. 16. Mean directions of paleocurrents in northern part of Age subgroup. A: Komeno gravel formation, B: Oizumi, Ichinohara and Kono formations, C: mean directions of cross beddings, D: mean directions of inclination of gravels.

Similar assemblages of diatom were obtained from Ma 1 and Ma 2. They live in lagoonal environment. The Maiko Shell Bed yielding *Clamys harimensis* belongs to this stage.

Stegodon akashiensis and *Elephas shigensis* are found in this stage.

h. Hacchoike stage.

This stage is a period when the Biwako-Osaka subsidence zone was continuously subsiding. It is characterized by alternations of marine and lacustrine environments in Osaka and Kyoto districts. The Hacchoike alternations are composed of alternating marine clays, Ma 3 - Ma 6, and lacustrine sands in the

horizon	site-number	locality	direction* of paleo-current	consistency ratio	type of cross-bed	number of measure-ment	number of set	thickness of set	average inclination
Komeno formation	A-207	Nishiyama	24	92.3	imbri.	15	-	—	31.7
	A-202	Hagihara	53	94.1	tabular	10	1		12.5
	A-204	〃	21	92.2	〃	4	1		30.0
	A-205	Shimotara	87	95.3	〃	10	1		36.0
	A-198	Makita	126	69.8	〃	10	3		17.5
upper part of Oizumi formation	A-210	Nishiyama	194	95.3	〃	15	1		34.7
	A-206	〃	212	89.8	〃	15	1	20	26.0
	A-209	Matsunoki	208	95.4	〃	11	1		34.5
	A-197	Makita	290	98.7	〃	15	1	20	22.3
	A-302	Iikura	279	98.5	〃	20	3	5-25	26.8
	A-150	Kamiaiba	237	99.3	〃	15	1	30	21.2
	A-178	〃	220	94.0	trough	15	3	50	13.4
	A-188	Shimoaiba	220	90.7	tabular	14	1	80	14.0
	A-220	Komeno	222	98.6	〃	15	1		20.3
	A-219	〃	247	96.3	〃	10	1		16.0
	A-217	〃	210	91.9	〃	15	1	65	25.5
	A-022	〃	230	97.9	〃	20	2	25	18.0
	A-172	〃	241	94.0	〃	10	1		16.4
	A-089	Higashitani	232	94.0	〃	15	1		15.7
	A-281	Rokkoku	243	93.7	trough	15	1	30	20.6
Pumice ash	A-164	Komeno	211	99.3	〃	15	2		23.2
	A-169	〃	226	98.7	〃	15	1		16.4
	A-299	Shimohira	187	98.3	tabular	13	2	10	21.1
lower part of Oizumi formation	A-280	Rokkoku	181	99.1	〃	8	1		15.3
	A-293	Obaraisshiki	240	98.0	〃	10	1	15	21.5
Kameyama formation	A-196	Iwahara	72	99.6	〃	51	4	10	18.1

Table 16. Results of measurements of the cross beddings of the Age sub-group. Paleocurrent directions are represented by anticlockwise angle from east direction.

Senriyama hill-lands and other hill-lands in the Osaka area. These marine clays often yield some mollusks which lived in an internal bay environment; *viz. Anadara granosa, Doshinia angulosa, D. japonica, Theora lubulica* and *Raeta pulluchela*. The lacustrine clays yield some fresh-water molluscan species living in the present Lake Biwa: *Anodonta, Lanceolaria, Vivipalus* etc.

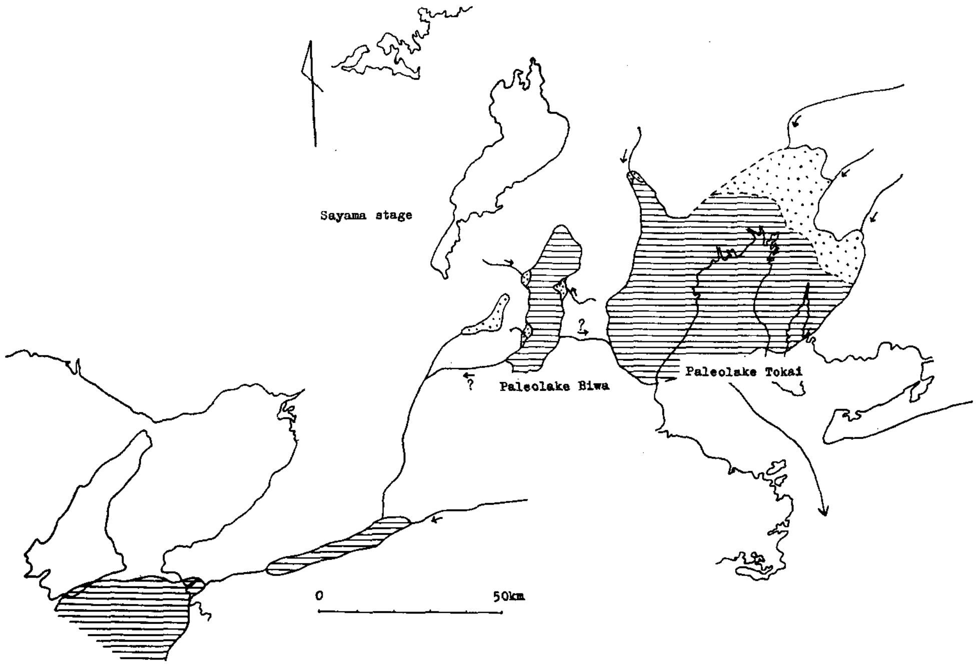


Fig. 17. Paleogeographic map of the Eastern Setouchi Province in Sayama stage (latest Pliocene). Dotted area: fluvial plain.

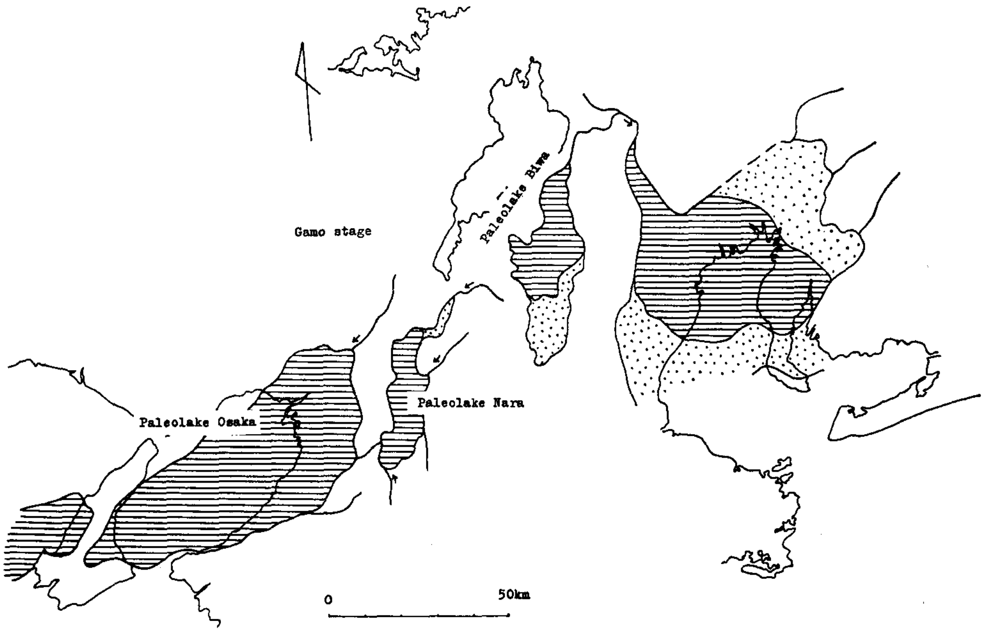


Fig. 18. Paleogeographic map of the Eastern Setouchi Province in Gamo stage (Pliocene-Pleistocene)

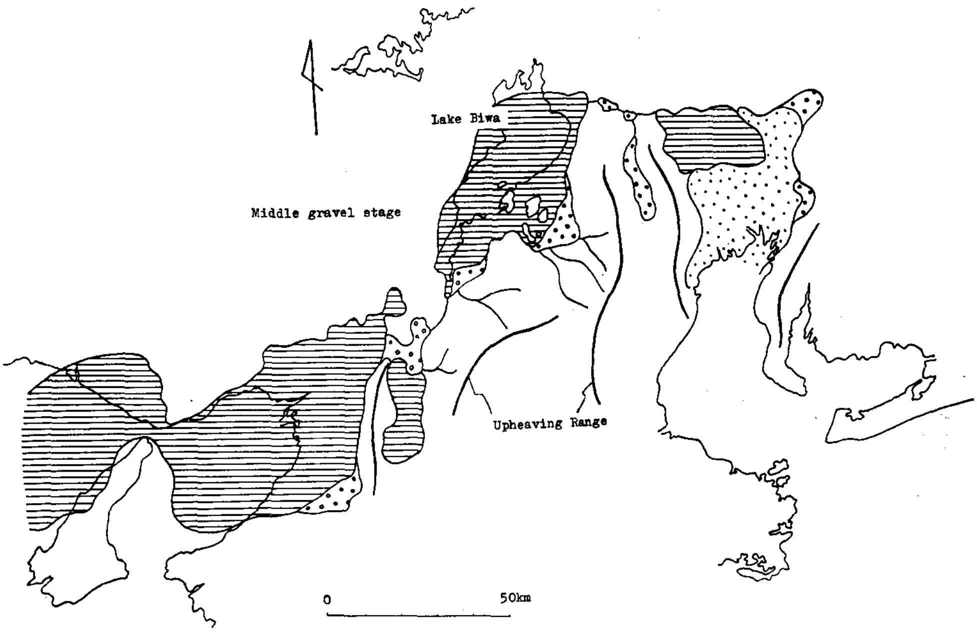


Fig. 19. Paleogeographic map of the Eastern Setouchi Province in Middle Gravel stage (early Pleistocene)

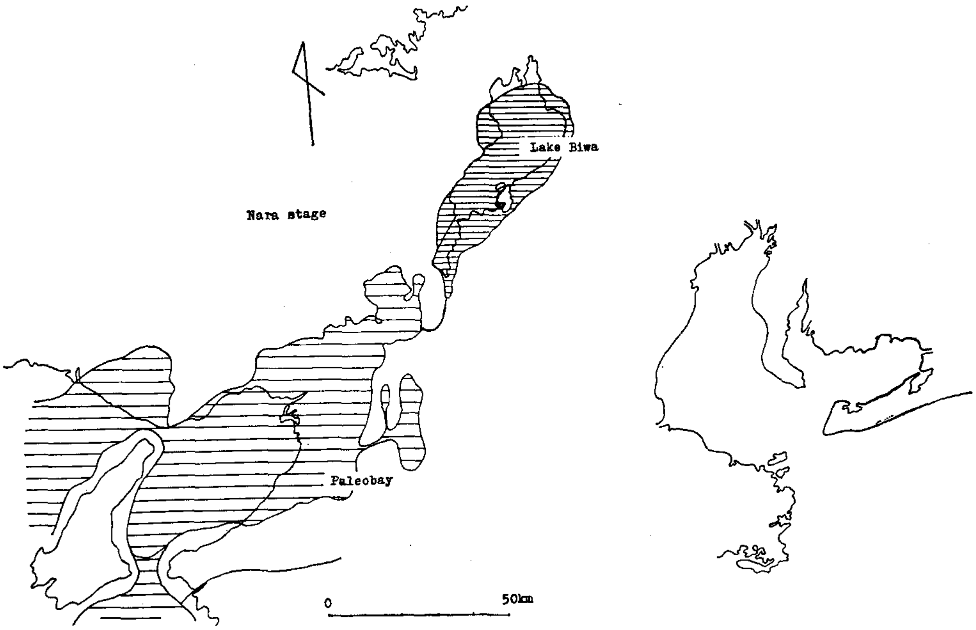


Fig. 20. Paleogeographic map of the Eastern Setouchi Province in Nara stage (early Pleistocene)

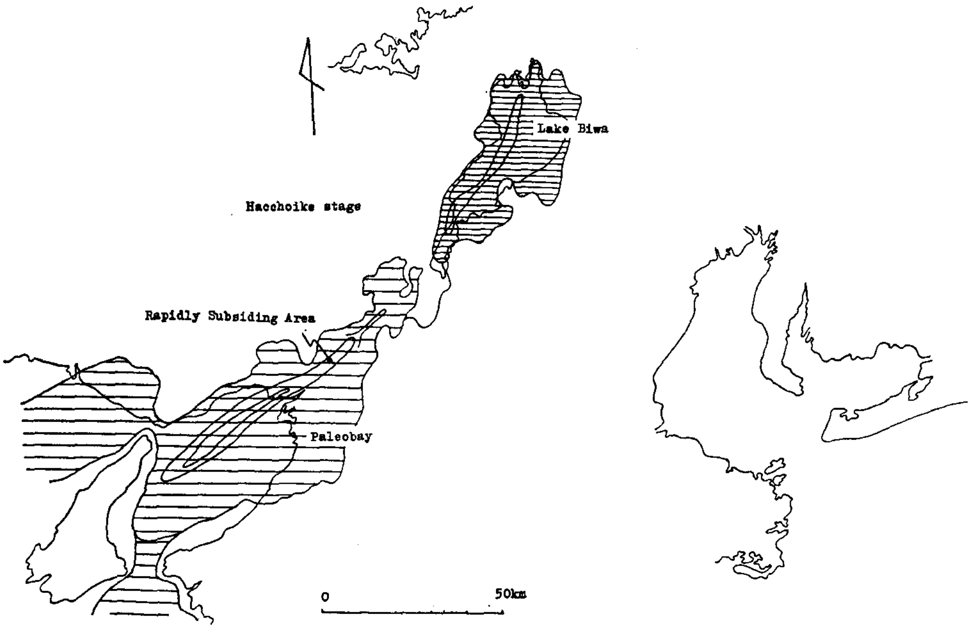


Fig. 21. Paleogeographic map of the Eastern Setouchi Province in Hacchoike stage.

Metasequoia disticha and other members of *Metasequoia* flora were exinct at the time of the horizon directly underneath Ma 3. *Elephas shigensis* and *Stegodon orientalis* existed in this stage.

The ancient lake Tokai had disappeared already, and Lake Biwa flooded over the area of Kosei.

i. Manchidani stage

This stage is characterized by marginal gravels with thin marine clays, Ma 7 and Ma 8, in lithofacies and climatic oscilations.

The crustal movement, indicated by these gravels, is called "Manchidani phase" of Rokko movement, which may be a beginning of the climax of the Rokko movement.

3) Rokko Crustal Movement

The crustal movement in the Plio-Pleistocene epoch was named the "Rokko movement" of southwest Japan (IKEBE, 1956). The Rokko movement has many features representing foundation foldings and faultings (MAKIYAMA, 1955). The tectonic history of the Kinki district can be summarized as follows:

a. Gently subsiding period in Seto stage

Beginning of gentle subsidence with E-W trend; the low land extended widely in Central Kinki. This may indicate the foundation folding.

b. Mizuno phase in Iga-Aburahi stage

The upheaval of the Kiso, Nunobiki and Takami Mountainlands and the appearance of the Ueno and Nobi Basins; basal gravels of the Plio-Pleistocene series in the Setouchi geologic province were deposited in these basins.

c. Sayama and Gamo stage

Development of the chain-like lakes; the southern part upheaved and the northern part of the Setouchi province subsided. Consequently, the centers of the sedimentary basins migrated toward the north as indicated by the turn of the opposite side of the paleocurrent directions.

d. Suzuka phase in Middle gravel stage

Rapid upheaval of the Kiso, Suzuka and Ikoma Mountain Ranges; many gravels were transported to the center of the sedimentary basins.

e. Nara stage

The subsidence of the entire area of the Biwako-Osaka subsidence zone and appearance of wide lagoonal environments.

f. Hacchoike stage

The rapid subsidence of the Biwako-Osaka subsidence zone; the internal bay environments spread over the northern part of Osaka Plain, Harima area and Kyoto Basin.

g. Climax of the Rokko crustal movement in Manchidani stage

The upheaval of mountainlands accompanied by the folding and faulting, then by the general upheaval of the whole area of the Setouchi Province took place.

Conclusive Remarks

The volcanic ash layers of the Plio-Pleistocene deposits in the Kinki and Tokai districts are utilized as very good key beds as they can be distinguished from each other by their various characters, and indicate a geologic time surface. By means of many volcanic ash layers the Plio-Pleistocene series distributed separately in several basins in the eastern Setouchi Geologic Province can be correlated fairly accurately.

The paleocurrent directions in each period can be deduced from cross beddings. Their vector means accord with other sedimentological features in the lacustrine deposits of the Kinki and Tokai district, and the crustal movement can be inferred from the changes in the mean directions of paleocurrents.

The migration of the sedimentary basins in the Plio-Pleistocene age based on the geologic time-surfaces of the volcanic ash layers and the paleocurrent directions are shown in Figs. 17-21.

The geologic history of the Setouchi Geologic Province in Plio-Pleistocene is summarized in Fig. 22.

Acknowlegement

The writer wishes to express his thanks to Prof. K. NAKAZAWA and Dr. S. ISHIDA for their guidance and encouregement. The writer is also indebted to Dr. J. MAKIYAMA, Dr. T. HARATA and the members of NISHIYAMA RESEARCH GROUP for their valuable suggestions and discussions.

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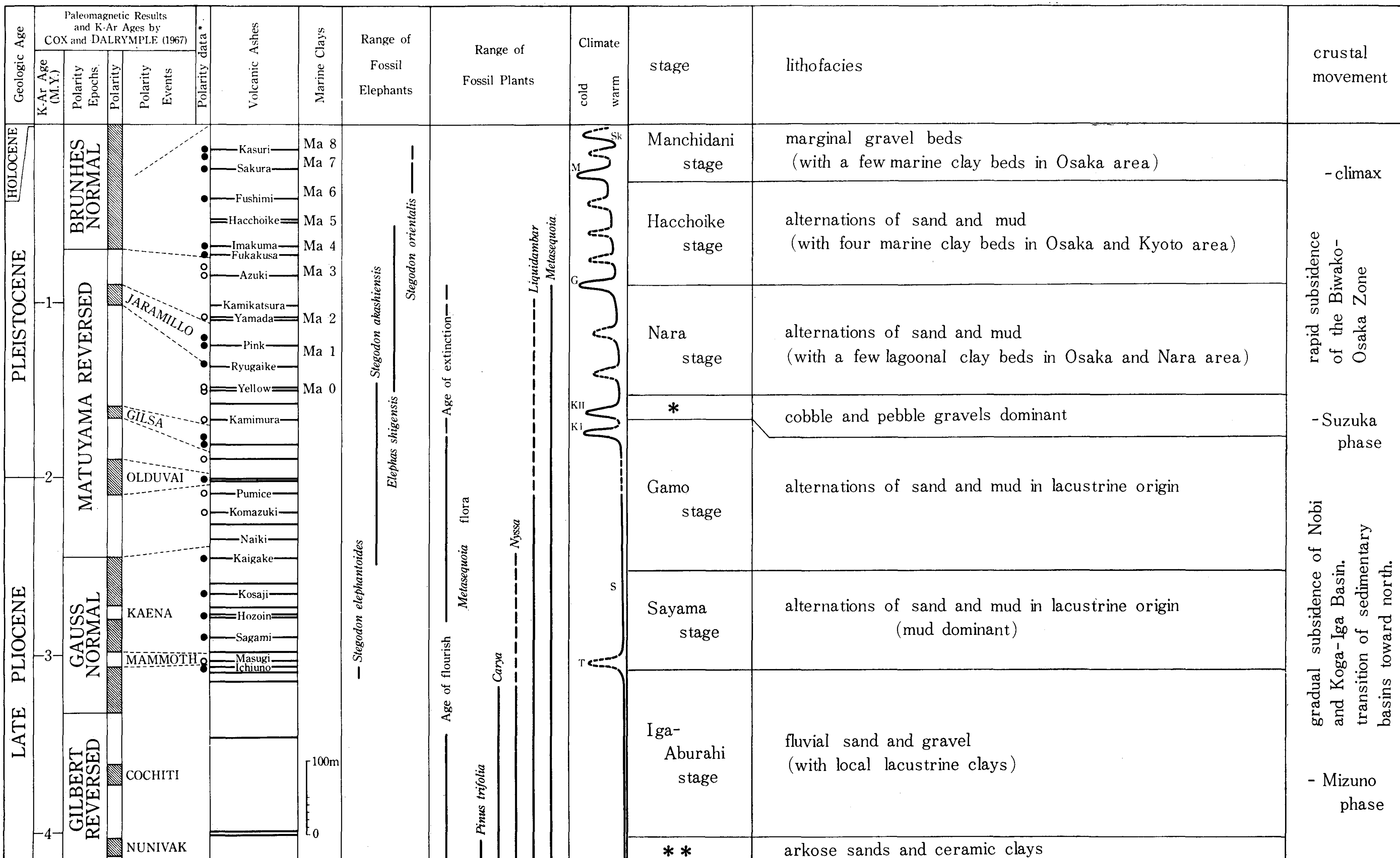

Fig. 22. Summarized geohistory of the Eastern Setouchi Geologic Province. *●: normal polarity, ○: reversed polarity. *; Middle Gravel stage, **; Seto stage, Sk; Shikori warm age, M; Manchidani cold age, G; Gokenya cold age, KII; Kamimura cold age II, KI; Kamimura cold age I, T; Terasho cold age.

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